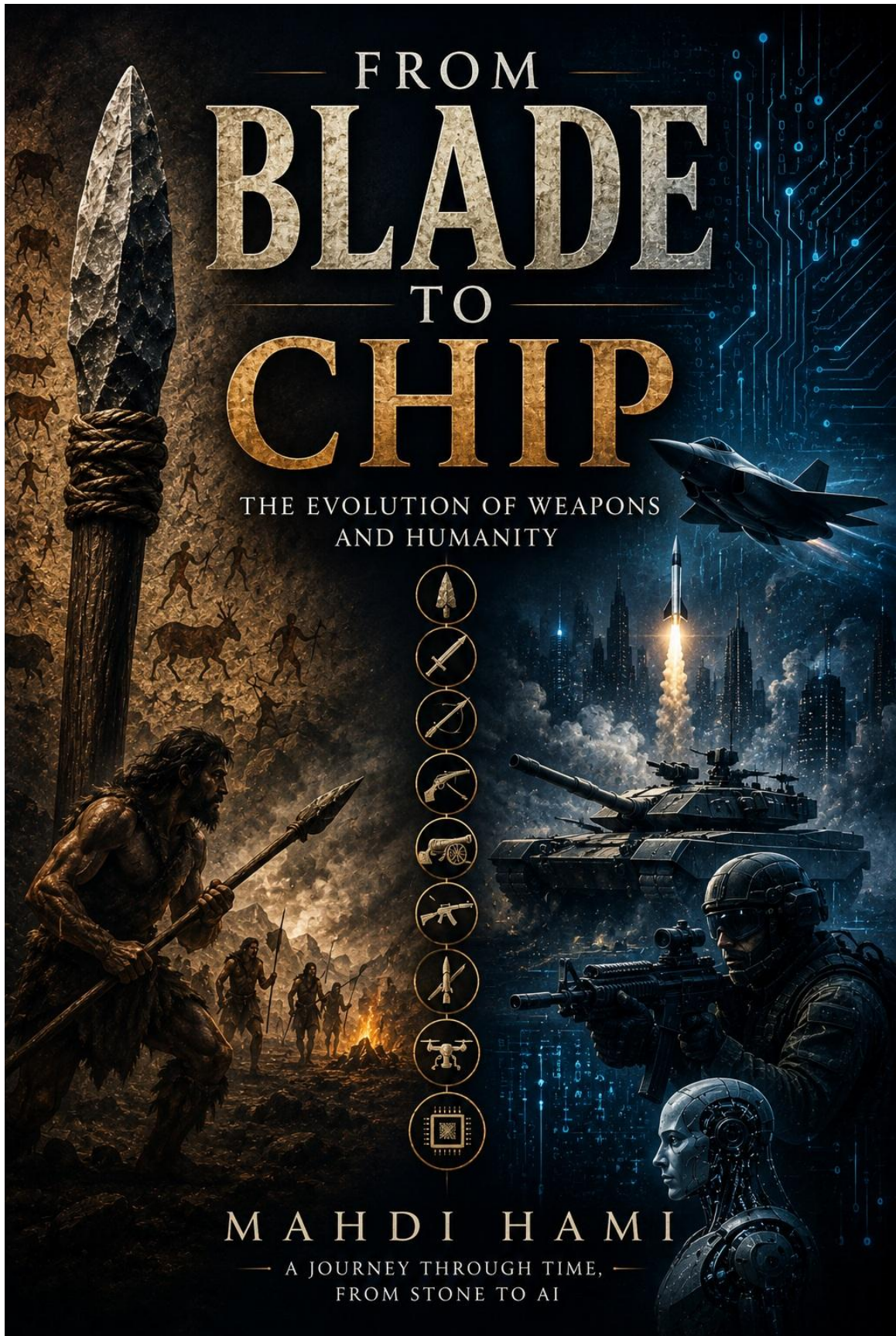




FROM BLADE TO CHIP

A Brief History of Human Weaponry

by Mehdi Hami

(Translated from the original Persian)

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All twenty-seven chapters of the original outline are included in this translation; where the source manuscript supplied for translation was missing a chapter (Chapters 10, 23, and 26 of the author's original numbering), the missing material was either supplied by the author in the course of translation (Chapter 10) or composed for this edition in a style and register consistent with the surrounding chapters, and clearly reflects the translator's own composition rather than the original Persian manuscript (Chapter 25, corresponding to the author's originally planned "Networks, Command, and War as a System").

Author's Preface

The history of weapons is not, in itself, merely a history of instruments of killing. It is the story of humanity's ever-changing relationship with violence, greed, and technology. Every weapon, before it is ever carried onto a battlefield, is first built in the human mind. That mental architecture takes shape from how a person perceives threat, takes root in their image of the aggressor, and matures through the struggle for survival, dominance, or security. To study weapons apart from the human being who makes them is to reduce the subject to a mere catalogue of mechanical objects. And to study the human being apart from the tools he has made and wielded gives us an incomplete picture of his historical existence. This book is written from the conviction that weapons are mirrors — they do not merely depict a scene, but represent the current that has taken shape within the human mind.

In pursuing this subject, the author has neglected no source that might shed light on the darkness surrounding any given weapon. From the technical catalogues of arms manufacturers to the memoirs of unknown soldiers, from interviews with traditional blacksmiths to the archives of defense ministries — all have found their way into this book, so that the reader never feels that anything has been withheld. This may be the first time a book on this subject, with such a breadth of sources, has been made available to Persian-speaking readers.

The reader may ask whether a book of this length and detail is even necessary in an age of information compression. The answer is that weapons, more than almost anything else made by human hands, deserve reflection and contemplation. The decision to build, buy, or use any one of these weapons can directly affect the lives and fates of anywhere from a single person to several million. One cannot dispose of the atomic bomb in a single paragraph, nor settle in two sentences the story of the transition from the stone blade to the bronze sword. This book wants to give the reader room to pause — a pause in which technical detail is woven together not for its own display, but to create both wonder and warning at once.

Throughout the writing of this book, one question has remained constant: where is the line between education and seduction? Could the precise description of a weapon produce fascination rather than awareness? Might a reader, captivated by the engineering elegance of a machine gun, forget its human cost? The answer arrived at here is that the best antidote to fascination is precision itself, paired with an honest reckoning of consequence. The more precisely we describe the angle of a sword's edge, the more real its wound becomes. The more clearly we explain the mechanism by which gunpowder releases its energy, the more terrible its explosion appears. This book, then, was written in such exacting detail not out of technical obsession, but out of a moral commitment to the integrity of the whole picture.

The images chosen for this book follow the same logic. Each image is not decoration but a historical or technical document that complements the text. Every effort was made to draw images from credible archives under open licenses, so that no barrier would stand between this material and students or researchers.

From here to the end of the book, the reader will encounter not a chronicle of military victories, but the transformation of the concept of violence itself. From the stone first lifted by human hands to the algorithm that may one day decide in humanity's place, one question has guided every page: what relationship does tool-using man bear to man without tools? It is hoped that, having read this book, the reader will come to share the belief that weapons are less an external threat than a mirror turned inward — and that this mirror, honestly faced, may one day shatter our sense that war is inevitable.

Introduction

This book is written on the foundational premise that weapons have not been a footnote to human history, but one of its principal engines. Instruments of war have never been merely the byproduct of technological progress; they have themselves driven profound change in social structures, political institutions, and the psychological patterns of human beings. From the first chipped stones to today's autonomous systems built on algorithms and artificial intelligence, every step in the evolution of weaponry has, at the same time, been a step in redefining the human being.

Unlike simplistic narratives that treat war as something innate or inevitable, this book shows that organized, armed violence is the product of a convergence of biological, environmental, cognitive, and social conditions. Early humans were not dominant hunters but vulnerable creatures within nature. Their passage from prey to hunter, and then to designers of complex weapons for killing and for establishing dominance through force or fear, was a gradual, multidimensional process — one without which modern war itself cannot be understood.

This book takes a historical-analytical approach, tracing the evolution of weapons in close connection with historical, social, and psychological change. Each section does not merely describe weapons technically; it seeks to clarify their consequences for the organization of war, the structure of power, and the human psyche. Within this framework, weapons are treated not as neutral objects but as active agents in the shaping of history.

The aim of this book is to offer a comprehensive, reference-quality picture of the evolution of weaponry — one that can serve as a citable resource for historians and social scientists, and equally speak to the serious reader who wants to understand how humanity, in its pursuit of survival and creativity, built instruments capable of its own destruction — and to expand the reader's understanding of weapons beyond merely hearing their names, toward genuine knowledge of the weapons themselves, their consequences, and the responsibilities they carry.

The Evolution of Weapons: A Timeline

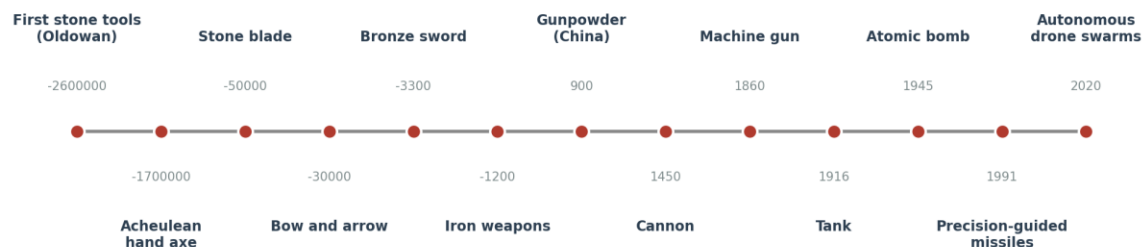


Chart: A simplified timeline of major weapons milestones across human history (author's diagram; dates approximate).

PART ONE

From Hunted to Hunter: Humanity in Nature

Chapter 1

Man as Prey in the Natural Ecosystem

When modern humans look back at their distant past, they often imagine themselves in the role of hunter and dominator. This image has roots in hero-centered narratives of evolution. But the evidence from paleoanthropology opens up an entirely different picture. Early humans, who lived across the plains of Africa and later on other continents between roughly two and a half million and forty thousand years ago, were never at the top of the food chain. They were vulnerable creatures who grappled daily with the threat of larger, faster, and better-equipped predators.

Taphonomic research (the study of what happens to remains after burial) at ancient sites has shown that the skeletal remains of early humans are frequently found alongside clear tooth marks from large carnivores. In many cases, these humans were prey, not predator. Extensive surveys across eastern and southern Africa have documented more than sixty fossil sites where hominin remains bear the archaeological signatures of predation. These traces indicate that bones were carried off by predators and then broken open to access the marrow. This data points to a high rate of predation — over a span of one to two million years, possibly exceeding four percent of all deaths in certain local populations. This pressure pushed humans toward heightened vigilance and collective defense.

The predators threatening early humans on Africa's open and semi-open plains formed a formidable lineup of large carnivores. The giant short-faced hyena (*Pachycrocuta*), roughly the size of a modern lion, had jaws capable of crushing thick bones and could make entire carcasses disappear. Ancient lions (*Panthera leo fossilis*), twenty to thirty percent larger than their modern counterparts, were skilled pack hunters that used ambush and coordination to bring down large prey such as wild horses and humped bison. Giant short-faced bears (*Agriotherium*), weighing over nine hundred kilograms, were mostly herbivorous but would, when necessary, attack both carcasses and living animals. But among these predators, one group posed a uniquely severe threat to early humans: the saber-toothed cats (*Machairodontinae*).

Fig. 1 — Homotherium, a species of saber-toothed cat, and the short-faced hyena

Fig. 2 — The ancient lion compared with the modern lion; the ancient bear's size compared with a human

In eastern and southern Africa, at least three genera of saber-toothed cats coexisted with early humans. *Homotherium*, a large cat (weighing two hundred to three hundred kilograms) with long limbs, hunted the open and semi-open plains and shows particular specialization in preying on the young of mammoths and other proboscideans. Its canines were serrated and reached roughly ten centimeters in length, evolved specifically for severing the arteries in a prey animal's neck. This predator was powerful enough to carry the skeletal remains of its kills over long distances, stripping carcasses completely clean of meat.

Megantereon, of medium build (sixty to one hundred kilograms) with exceptionally powerful shoulder and forearm musculature, was an ambush predator that surprised its prey from within thickets and scattered woodland. Its canines were straight, dagger-shaped, and reached up to eighteen centimeters in length. This cat could bring down a human with a single leap of three to four meters and pierce the skull or neck of its prey with its fangs. Carbon isotope evidence shows that *Megantereon*'s diet differed from that of othersaber-tooths, and it is considered more likely to have included large primates — including early humans — among its prey.

Fig. 3 — Megantereon; Dinofelis

The third and perhaps closest threat to humans was *Dinofelis*. This medium-sized cat (thirty to eighty-eight kilograms, roughly the size of a modern leopard or jaguar) had exceptionally powerful, sturdy forelimbs evolved for gripping and holding prey. *Dinofelis* preferred to ambush from semi-forested habitats and thickets, and its prey consisted largely of baboons and other primates. At South African fossil sites such as Swartkrans and Kromdraai, hominin skeletons — including *Paranthropus* and *Homo habilis* — have been found alongside *Dinofelis* remains. Some of these hominin skulls show two distinct puncture marks spaced seven to eight centimeters apart, matching the spacing of *Dinofelis*'s canines, suggesting the cat pierced the skull with its fangs, targeting the brain or spinal cord. Although more detailed

carbon isotope analysis later showed that *Dinofelis*'s primary diet consisted of grazing animals such as early cattle, the fossil record nonetheless provides undeniable evidence of attacks on hominins and other primates.

From a biological standpoint, the human body was not built for physical combat. The absence of long, cutting canine teeth, the lack of lethal claws, the absence of thick hide, and the inability to sprint explosively all made humans easy prey. Comparative studies show that the human bite force is roughly one-half to one-third that of a chimpanzee's. Human upper-body muscular strength is far lower than that of the great apes. Even running speed, contrary to popular belief, is only middling among mammals. The fastest human alive today, with a maximum speed of 44 kilometers per hour, stands no chance of outrunning a mountain goat at 80 km/h, a lion accelerating to 56 km/h, or a cheetah reaching 120 km/h. What placed humans at risk was not merely physical weakness, but the absence of a clear behavioral algorithm for defense. Every predator in nature carries an innate repertoire of defensive behaviors; early humans, still in transition from an arboreal to a terrestrial existence, had not yet evolved that algorithm.

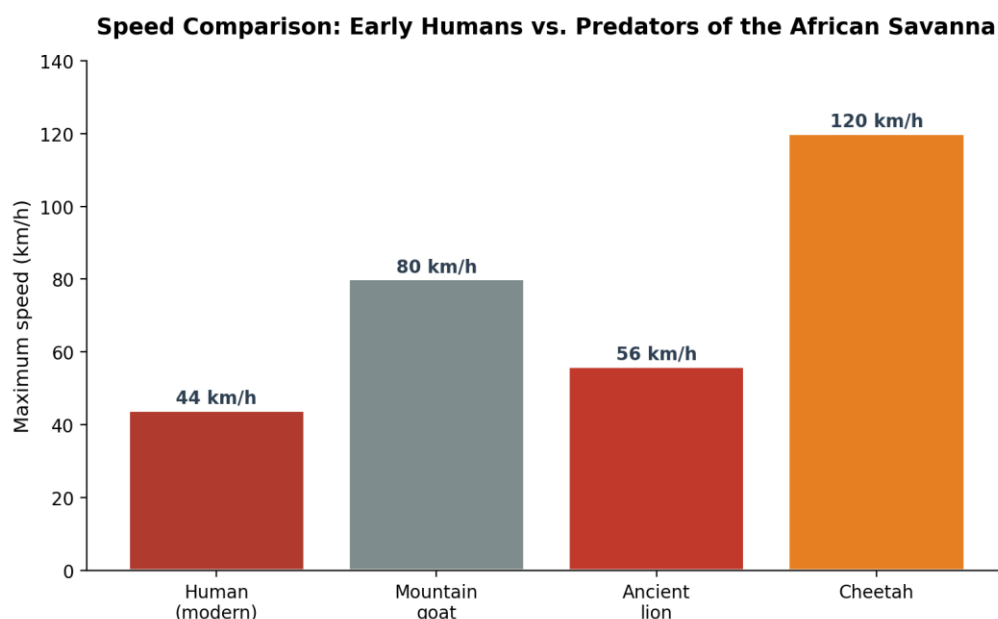


Chart: Maximum running speed of modern humans compared with selected predators and prey of the African savanna (author's diagram).

Some anthropologists estimate that the rate of predation in certain early human populations during the Plio-Pleistocene may have reached six to ten percent of adult deaths. This means that out of every ten adult humans living in a given area, at least one fell prey to large predators. Even in populations with lower rates, the threat of predation was severe and persistent enough to strongly bias the human nervous system toward threat vigilance. Early humans evolved to register even ambiguous cues as potential threats. This oversensitivity, though sometimes a false alarm, saved their lives in cases where the danger was real — and sometimes amounted to nothing more than empty, groundless fear.

In an environment saturated with threat, fear played a vital role. Fear is the sympathetic nervous system's physiological response to potentially dangerous stimuli, involving an elevated heart rate, dilated pupils, increased blood flow to the muscles, and adrenaline release. To survive, early humans had to recognize and respond to signs of danger quickly. Those who were faster at this recognition had a greater chance of passing their genes to the next generation. In this way, threat vigilance gradually became embedded in the human brain.

But fear in early humans was not merely a moment-to-moment alarm mechanism. According to neuro-anthropological models, *Homo erectus* and *Homo habilis* likely possessed a notable capacity for anticipating danger. This capacity for proactive cognition results from activity in the frontal region of the brain, particularly the prefrontal cortex, which was gradually enlarging in early humans. Craniometric studies show that *Homo habilis* had a cranial capacity of roughly 550 to 680 cubic centimeters, while *Homo erectus* reached 850 to 1,100 cubic centimeters. This additional volume, roughly 300 cubic centimeters, was concentrated mainly in the frontal and parietal lobes, regions associated with planning, decision-making, and anticipation.

The evolution of this capacity allowed humans to move from pure reaction to calculated action. A hyena or a lion is, fundamentally, an instinct-driven creature: on sighting prey, it attacks immediately. But early humans could estimate distance, weigh escape options, recall the route to shelter, and decide quickly on the best course of action. This major advantage, despite physical weakness, dramatically increased their chances of survival. Individuals who developed this capacity further were more likely to pass their genes to the next generation. For this reason, threat vigilance and predictive capacity became inseparable components of the human mind.

Group living was the engine of survival against environmental threats. A lone human stood no chance against a leopard or hyena. But a group of ten humans, using stones, sticks, shouting, and coordinated movement, could drive off even a leopard or chase a lion away from a fresh kill. For this reason, early humans naturally lived in groups of twenty to fifty. This group size was, on the one hand, large enough to allow for collective defense and cooperative hunting, and on the other, small enough for the local food supply to sustain.

Group living was not merely a mechanical aggregation. It quickly became a social structure with defined roles. In each group, those with sharper eyesight took on the role of lookout. The strongest and most skilled stood at the front line of defense. Older members, who had more experience recognizing animal behavioral patterns, served as advisors and planners. Women and children were responsible for tending the fire and gathering roots and fruit. This division of labor was the earliest example of a complex social system — one that would later be reproduced in the form of armies and command structures.

Archaeological evidence shows that early human settlement sites were often chosen for their natural vantage points. This deliberate site selection reflects collective defensive planning. At some East African sites, large caches of stones have been found at the edges of camps, likely serving as ammunition stockpiles against predators. When danger approached, the whole group would coordinate to gather stones, then unleash a coordinated barrage against the attacker.

This coordination in hunting and defense required effective communication. Early humans coordinated using a combination of vocalizations, hand and body gestures, and later, sign language. Studies of brain morphology in *Homo habilis* and *Homo erectus* fossils show gradual growth in Broca's area (the speech production center) and Wernicke's area (the language comprehension center) in these species. Although they were not capable of producing complex language, they could convey concepts like "it's dangerous here" or "come from that direction" through a combination of sounds and gestures. This rudimentary but effective communication system dramatically increased the capacity for defensive coordination.

The importance of collective warning cannot be overstated. In nature, predators rely heavily on surprise. But if a human group has lookouts posted in several directions, a predator cannot approach unnoticed. Even if it does get close, a single warning shout gives the whole group a few extra seconds to react. Against a predator, even two extra seconds can mean the difference between life and death. Early humans survived on precisely this thin margin of safety — and if we look closely, traces of this same collective behavior remain with us today, in things like barbed wire and the watchtowers of military and border-patrol zones.

Among the enduring debates in evolutionary anthropology is the long-standing question of to what extent early humans were hunters and to what extent scavengers. Archaeological data suggests that early humans, particularly *Homo habilis* and *Homo erectus*, were largely opportunistic, confrontational scavengers who approached fresh kills using high-risk tactics. They would move toward the site of a recent kill, use noise and stone-throwing to drive the primary predators away from the carcass, then quickly cut off the meatiest portions and carry them to a safe location.

Fig. 4 — Stone tools found in Olduvai Gorge, Tanzania (Oldowan industry)

The earliest stone tools, discovered in Tanzania's Olduvai Gorge, date back roughly 2.6 million years. These were river pebbles that, with a few strikes, were given a sharp, jagged edge; this rudimentary method of shaping stone is known as the Oldowan industry. A somewhat more refined method, known as the Acheulean industry, emerged around 1.7 million years ago and marked a tremendous leap in tool design. The Acheulean hand axe was flaked on both faces to create symmetry, with a pointed tip and a cutting edge running around its perimeter. These axes were made from harder stone and could weigh up to two kilograms. Many of these axes have been found buried at sites with no accompanying bone or hunting remains whatsoever, meaning they were not tools at all, but symbols.

Fig. 5 — An Acheulean-style hand axe found at Dahtel, Hormozgan Province, Iran

The transition from scavenging to active hunting, which accelerated from roughly five hundred thousand years ago, had profound effects on ecosystems worldwide. Humans equipped with more advanced tools gradually rose to the top of the food chain. The relentless hunting of certain large animals by hunter-gatherer humans was likely one factor behind the extinction of the great Pleistocene megafauna. In Australia, roughly forty-five thousand years after human arrival, eighty-five to ninety percent of large animal species went extinct. In the Americas, more than seventy large-bodied species disappeared within less than two thousand years of the arrival of human hunters.

At this stage, there is still no solid evidence of organized warfare. But the earliest signs of interpersonal violence begin to appear. A fossil known as the "BC skull," found in the Turkana region of Kenya, belongs to a *Homo erectus* individual from roughly one and a half million years ago. The skull bears two impact marks made with a stone tool, inflicted before death, during the individual's lifetime. This is among the oldest known evidence of deliberate killing in human history. But this violence was likely the kind that arises over resources, not war in the modern sense we recognize today. Groups of humans did not form ranks and march against one another in battle formation. Violence was individual, reactive, and largely spontaneous. Still, these scattered acts of violence planted the first seeds of the concept of "the other" in the human mind. The stranger was no longer simply another human being; he was a potential threat.

Chapter Summary

This chapter has shown that at the very starting point of their history, early humans were not hunters but prey. With a weak body lacking natural weaponry, they lived within an ecosystem ruled by large predators. In response to this vulnerability, four parallel mechanisms gradually evolved: threat vigilance and fear, group cohesion and cooperation, toolmaking, and the gradual transition from scavenging to hunting. At this stage, one cannot yet speak of "weapons" in the specialized sense of the word. Tools were multipurpose, and the line between a hunting tool, a personal defense tool, and a tool for killing one's own kind was tangled and ambiguous. Nonetheless, the groundwork for the transformation of tool into weapon had been laid. Humans now knew that a tool could be used to kill another living being. This knowledge gradually accumulated across generations and became cultural memory — the subject of Chapter Two. Humans also learned that a stranger could be killed, eliminated, and their resources seized. From this moment on, violence was no longer merely a biological reaction to repel a threat; it became a strategic option for acquiring resources and reinforcing group identity. This shift opened the path toward the making of human history.

Chapter 2

Fear, Group Cohesion, and the Birth of the Threat-Oriented Mind

Fear was humanity's first shared experience with the world around it. Before tools were made, before complex language took shape, and before violence became an organized act, the human brain was built for survival, and so humans learned to fear. This fear was not a passing reaction but a stable framework for understanding the environment, one that would later shape the evolution of weapons both directly and indirectly. Yet fear in early humans, contrary to common belief, was not a psychological defect. Fear was a survival tool, one that, in preserving human life, was every bit as important as the sharpest stone blade; we might even call fear the first weapon humanity ever possessed, though it was the first non-physical one. The difference between a physical tool and fear was that a stone blade could be touched, held, and identified, while fear flowed through the brain and nervous system, operating as an automatic hormonal response.

The nervous system of early humans evolved to process signs of danger faster and more powerfully than signs of reward. In cognitive neuroscience, this is called negativity bias. An early human walking through the brush who spotted a dark, moving shape among the bushes would immediately have his brain interpret it as a lion and trigger a fight-or-flight response, even if the shape was merely the shadow of a rock or a tree branch. The cost of this error, a false alarm, was trivial: a few wasted seconds, a small burst of spent energy. But the cost of the opposite error, failing to notice a real lion, was death. It is therefore no surprise that, across thousands of generations, the human brain became strongly biased toward over-detecting threat. This tendency persists in modern humans, showing up as fear of the dark, fear of sudden noises, and fear of confined spaces. But in the Paleolithic, this tendency was a decisive advantage.

Paleoneurological evidence, based on measurements of cranial cavity size and shape in fossils, shows that the brain regions involved in processing fear, particularly the amygdala, hippocampus, and anterior cingulate cortex, grew significantly larger in *Homo erectus* compared to *Homo habilis*. The amygdala, an almond-shaped structure deep within the temporal lobe, is responsible for detecting threat and triggering the automatic fear response of elevated heart rate, adrenaline release, and dilated pupils. The hippocampus is responsible for recording and retrieving memories tied to the place and time of threatening events; it allowed early humans to build a kind of fear map of their environment: which valley is dangerous, which spring is safe, which escape route is fastest and most effective. The anterior cingulate cortex generates a sense of unease and ambiguity when facing uncertain situations, pushing humans toward caution and away from hasty decisions. The relative enlargement of these regions in *Homo erectus*, with the amygdala roughly forty percent larger by volume than in *Homo habilis*, based on cranial reconstructions, points to the growing importance of fear and threat management in this species' evolution. In other words, *Homo erectus* was a professional at being afraid. He was afraid, but his fear was vigilant and calculated, not blind instinct; this wakeful fear allowed him not only to react to immediate threats but to anticipate threats yet to come.

To better understand this mindset, we might use the metaphor of a threat filter. Every sensory signal entering the early human brain, through sight, hearing, smell, or touch, first passed through a filter whose job was to detect any resemblance to threat patterns stored in memory. These patterns were stored in the hippocampus as rows of sensory features: shape, size, color, smell, sound. If an incoming signal resembled any stored threat pattern, even a weak or partial match, the fight-or-flight response fired immediately. If no such resemblance existed, the signal was classified as neutral or beneficial. This filter was so powerful that it sometimes produced almost comical results: a person spotting a strangely shaped rock on the horizon might mistake it for a sleeping lion, and even after getting closer and realizing it was just a rock, his heart would keep pounding and his skin would break into a cold sweat for a few moments longer. This is known as a misplaced threat response, and we see it in modern humans in things like the fear of a cockroach, which poses no real danger, or fear of vague shapes in the dark.

From an evolutionary standpoint, this oversensitivity was a sound investment. Though it sometimes wasted energy and time, in the cases where a real threat was present, it saved lives. For this reason, individuals with a more sensitive filter passed their genes on more successfully. As a result, modern humans have inherited this same threat-oriented mind from their ancestors, even though we now live in an environment where large predators are rare; abstract threats such as job stress, fear of social rejection, or anxiety about the future have simply taken their place. This is why anxiety disorders are so prevalent in modern humans; roughly thirty percent of the population experiences some form of

anxiety disorder over the course of their life. Our minds are still running on the default settings of the African savanna, even as we live in city apartments.

The threat-oriented mind had profound consequences for how early humans perceived "the other," those outside the group. Every new individual who entered an early human's field of vision first passed through the threat filter. Signs such as scarring, unusual clothing, aggressive behavior, or the carrying of tools, especially a spear or club, were quickly classified as threats. Even in the absence of such signs, the mere presence of a stranger was itself a potential threat, since by definition a stranger is unknown, and from the standpoint of the threat filter, the unknown is the most likely candidate for danger. This is why rituals of introduction, such as showing an open, empty palm to prove one was unarmed, offering a gift of stone or food, friendly dances, or intermarriage between two groups or tribes, evolved in tribal societies to temporarily disable this threat filter and allow peaceful interaction. Archaeological evidence of gift objects, decorative stones, pierced sea shells, obsidian fragments found hundreds of kilometers from their source, points to the existence of gift-exchange networks and likely the exchange of women for intertribal marriage among different groups. Such exchange was essential for reducing hostility, building weak but vital ties, and expanding genetic diversity. But it always carried risk: a group could feign friendship to weaken another group's defenses and then attack.

For this reason, full trust in a stranger was an anomaly. The default rule was default distrust. Early humans did not trust a newly arrived stranger until proven otherwise; rather, they distrusted him until proven otherwise, and proving otherwise required time and cost, including gifts, friendly behavior, and sometimes the taking of hostages. This default distrust was later reproduced across every political and military institution: great-power rivalry on the international stage, espionage, non-aggression pacts always pursued with suspicion, and cautious diplomacy all trace their roots back to this same Paleolithic, threat-oriented mind.

A History of the Handshake

In early human societies, where a stranger was almost always synonymous with a potential enemy, any encounter with an unknown individual activated the threat filter. In such an environment, the need for a non-verbal ritual to neutralize initial suspicion became vital. To this end, two parties would approach each other with empty hands and arms hanging loose, showing their open palms as proof that they carried no weapon, and then clasping each other's hand, likely to confirm that no knife or blade was concealed up a sleeve. This formed a kind of temporary declaration of peace. This primitive ritual, rooted in an almost obsessive fear of self-defense, was later formalized in Greek and Roman civilization and became a symbol of agreement, loyalty, and good faith, even as its original function, neutralizing fear of the stranger, remained at its symbolic core.

To preserve their cohesion against both internal and external threats, human groups needed symbolic mechanisms that went beyond the sheer necessities of practical cooperation, such as division of labor and food-sharing. These mechanisms included shared rituals, shared myths, and sacrifice, sometimes human sacrifice.

Shared rituals: From roughly one hundred thousand years ago, clear evidence of burial rituals appears among early Homo sapiens, and even, in some cases, among Neanderthals. At Skhul Cave in Israel, the skeleton of a woman from roughly ninety thousand years ago was found with her hands folded over her abdomen and surrounded by the horns of a mountain goat. At the Qafzeh site in the same region, the skeleton of a hunter from roughly one hundred thousand years ago was buried with personal items, including pierced sea-shell fragments once worn as a necklace. At Shanidar Cave in Iraq, the skeleton of a Neanderthal known as Shanidar 4 was found buried with pollen from medicinal plants, including wild roses, borage, and yarrow, suggesting that Neanderthals too buried their dead with flowers. These burials were not merely a hygienic practice; they were signs of belief in an afterlife, or at least of respect for the dead. Shared burial rites forged a bond between the living and the dead, binding the group into an imagined community that crossed the boundary of death itself. This sense of generational continuity reinforced internal cohesion, since death was no longer an absolute end but a continuation of life in collective memory and in the earth, through the bones of ancestors.

Shared myths: Indirect evidence of shared myths comes from cave paintings such as those at Lascaux and Chauvet in France. These paintings, some dating back thirty-five thousand years (Chauvet) and others to seventeen thousand years (Lascaux), depict hunting scenes of bison, horses, deer, and cave lions, alongside composite beings, half-human and half-animal, such as the so-called Sorcerer of Lascaux, which has a human body and a bird's head. Historians of

religion, such as Mircea Eliade and Joseph Campbell, argue that these paintings were part of totemic myths, stories that traced a group's origins back to a sacred animal, a totem. If every member of a group believed themselves descended from the cave lion, their relationship to one another became one of supernatural kinship rather than merely a network of temporary cooperation. These myths formed the strongest social glue imaginable, since to oppose them was not merely to break a custom but to commit blasphemy against one's kinship with the totem and one's ancestors. Shared myths also provided a pretext for sacrifice, including human sacrifice. In some cave paintings, scenes appear of a human figure falling or being wounded by a powerful animal, or by a human wearing an animal mask, which may represent a depiction of totemic sacrifice.

Human sacrifice: Ritual violence has been documented in many ancient societies, and even in some more recent ones, such as the sacrificial practices of the Inca and Aztec. The oldest evidence, though still heavily debated, likely comes from the Jebel Sahaba cemetery in Sudan, dated to roughly fourteen thousand years ago, where skeletons bear marks of multiple, patterned wounds and embedded arrowheads, as though the victims had undergone some kind of ritual sacrifice to gods or ancestors. In some of these skeletons, arrowheads are found not in the bones typically struck during hunting or war, but in the region of the heart and abdomen, more closely associated with ceremonial sacrifice. Human sacrifice, often carried out during times of crisis such as drought, famine, disease, or defeat in war, served several functions: strengthening group bonds by creating a common enemy, often a captive chosen from an outside group, and turning that person into a scapegoat; securing the favor of supernatural forces to resolve the crisis; purifying the group of impurity; and demonstrating the group's power to rival groups. Seen this way, human sacrifice represents the earliest form of ritual warfare, in which killing the other is done not for economic resources, but for symbols: totems, ancestors, gods, and collective belief. This was an important step toward ideological warfare, in which the goal is not merely the physical killing of an enemy, but his symbolic humiliation and the glorification of one's own gods and values.

The central argument of this book is that war was not the result of a conscious choice for aggression, but the result of a long chain of gradual responses to fear. This chain can be summarized in three steps.

First step: Fear of natural threats, large predators, disasters, disease, led to group cohesion. Early humans instinctively grasped that survival within a group was far easier than survival in isolation. Within these groups, cooperation and division of labor took shape, and taboos against in-group violence were established, reinforced through social punishment: exclusion, shaming, and, in severe cases, execution.

Second step: Group cohesion led to the recognition of the other, anyone who was not a member of the group. Neighboring groups that lived within a shared territory gradually developed symbolic boundaries: a shared language, bodily markings, dress, burial customs, myths. Anyone lacking these markers was a stranger, and because he was unknown, he was inherently regarded as a threat. Even if the stranger displayed friendly behavior, suspicion still prevailed. The stranger remained a potential enemy until proven otherwise, through accepting the group's norms, offering gifts, or providing hostages.

Third step: The recognition of the other led to preemptive violence. If a stranger approached a group's territory and the group could not quickly confirm that he had no hostile intent, the most rational course of action, from the standpoint of the threat filter, was to strike first and ask questions later. The cost of a false positive, attacking an innocent stranger, was low; the cost of a false negative, failing to attack a genuinely hostile stranger, was fatal. This logic of catastrophic cost led to the killing of strangers, men, women, and children alike, with no declaration of war whatsoever. For the fleeing stranger, this violence is an unjust massacre. For the attacking group, it is preemptive defense. These two opposing narratives would repeat throughout every human conflict to come.

The oldest evidence of group conflict in the Paleolithic comes from the Jebel Sahaba site in Sudan, dated to roughly fourteen thousand years ago. At this cemetery, fifty-nine skeletons were found, more than forty percent of them bearing cut marks from stone tools or embedded spear or arrow points. Many of these bodies were later collected by survivors and buried ceremonially, a pattern pointing to a stable group unit that valued its dead. It also suggests that war was no longer a random skirmish but a recurring, planned event, carried out with standardized weapons, resulting in regular casualties.

At Neanderthal sites in Europe, such as San Cidres in Spain (roughly forty-nine thousand years ago) and Krapina in Croatia (roughly one hundred thirty thousand years ago), cut marks on human bones have been attributed to war cannibalism intended to humiliate an enemy. Neanderthals, who went extinct roughly forty thousand years ago, likely

experienced sustained conflict with modern humans migrating from Africa into Europe. Though climate change and genetic absorption also played a role, the evidence suggests that modern humans, with better organization, longer-range weapons such as the bow, which Neanderthals lacked, and likely larger populations, were able to defeat the stronger but slower Neanderthals in scattered confrontations.

Statistical research on human remains in Europe shows that the rate of interpersonal violence resulting in death during the Paleolithic was quite low, roughly two to five percent of all deaths. With the transition to the Neolithic and the advent of agriculture, this rate rose to fifteen to twenty-five percent. Complex weapons and organized warfare, then, were less the product of early human weakness than of resource abundance and population growth in the Neolithic. But the seed of it was planted in the Paleolithic, in that very moment when humans moved from fearing the stranger to killing him.

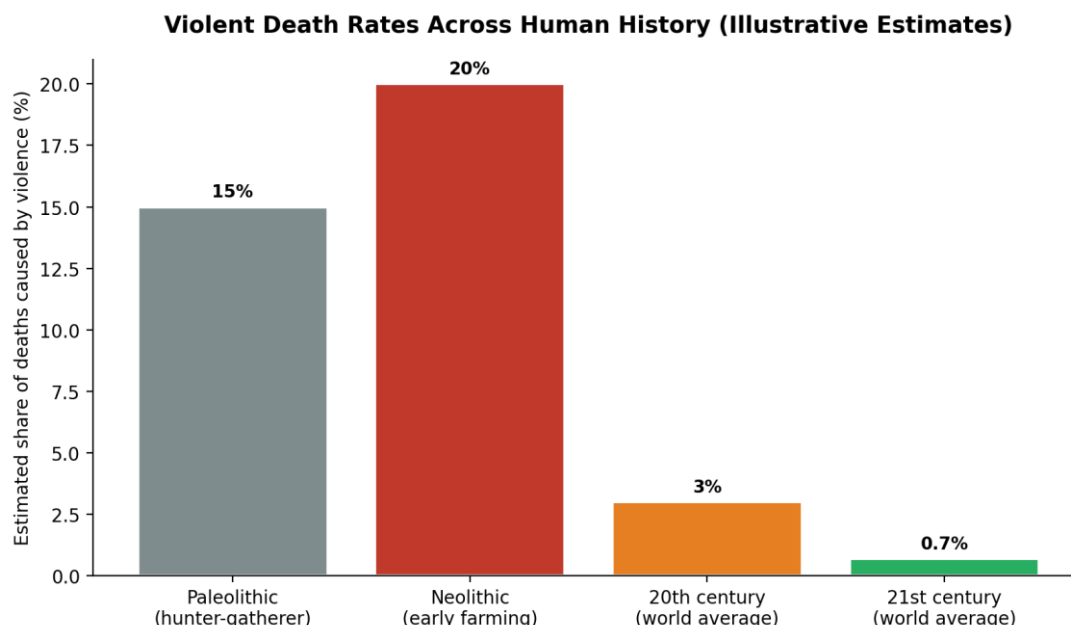


Chart: Illustrative estimates of the share of deaths attributable to violence across broad eras of human history (author's diagram; figures are approximate and contested among researchers).

Chapter Summary

Chapter Two has shown that fear was a constructive force, not merely a destructive one, in the psychological history of humankind. Fear pushed early humans toward group cohesion, cooperation, and coherent social structure. Cohesive groups created symbolic mechanisms, burial rites, totemic myths, and likely sacrifice, to preserve their unity and distinguish themselves from strangers. Within each group, violence was taboo. Between groups, violence was considered wise and necessary, a form of preemptive defense. This moral duality was rooted in the threat-oriented mind.

At this stage of history, one still cannot speak of war in the organized, military sense. Conflicts were scattered and small, and largely reactive. But the psychological and social groundwork for the birth of war was fully in place: humans could regard the other as an enemy, identify with their own group against that enemy, and regard preemptive violence as a sacred duty. These three capacities are precisely the preconditions that, in Chapter Three, would be put into action with the emergence of more specialized weapons and better-organized groups.

Chapter 3

Cooperative Hunting and the Origins of Planned Violence

Humanity's transition from a being that merely reacted to threat, to a being capable of planning acts of violence, ranks among the most decisive events in the biological and cultural history of our species. This transition did not arrive through some sudden leap in physical power or instinct. It was the gradual result of an evolving organization of collective behavior. Cooperative hunting was the first true arena in which violence shifted from an individual, reactive act into a purposeful, repeatable, and improvable process. Cooperative hunting taught humans that to achieve a goal, killing an animal, they had to design specific steps in advance: locating the prey, encircling it, driving it toward an ambush point, and finally delivering the fatal blow. This same logical sequence would later be reproduced on a far larger scale, with far more complex goals, in the form of military tactics and strategy.

At this stage, tools took on a new role. A tool was no longer merely an extension of the hand, used randomly or in the moment. It became part of a plan. A spear that had once been nothing more than a sharpened stick was now defined within the framework of a hunting strategy: the type of spear, heavy for a static strike, light for throwing, the number of spears available to each hunter, the throwing angle relative to the prey's direction of movement, the coordination of multiple throwers to cover different angles. These considerations were the earliest signs of engineering thought applied to violence. Humans were no longer just making tools; they were planning how to use them, and revising those plans based on results in the field. This cycle, plan, execute, gather feedback, revise, would later run through every domain of military technology.

Cooperative hunting also taught humans that distance could be an advantage. Hunters who pursued and exhausted their prey from afar risked their lives far less. Spear-throwers operating from a long-range ambush were far less likely to be injured than someone approaching the animal with a stone knife. This experience gradually became a general principle: the farther you are from your target, the safer you are, while still being able to kill it. This principle would later be applied to every long-range weapon that followed, from the bow to the missile.

Early humans employed different strategies depending on the size, speed, and behavior of the animal. For small, fast animals such as gazelles and hares, persistence hunting was used: a group of hunters took turns running the animal down until it collapsed from exhaustion. For large, powerful animals such as mammoths and woolly rhinoceroses, drive hunting was common: hunters, making noise and throwing stones, herded the animal toward a cliff or ravine where spear-armed hunters lay in wait. For mid-sized animals such as wild boar and deer, ambush proved effective. Each method required different tools, timing, and coordination, and this strategic diversity laid the groundwork for complex tactical thinking.

The stone blade was a qualitative leap in the history of cutting technology. Unlike the Acheulean hand axe, an all-purpose tool, the stone blade had a specific, specialized purpose built into its design from the outset: cutting soft tissue, living or dead. The stone blade was produced using a method known as the Levallois technique, in which a craftsman first shaped a stone core into a tortoise-shell form, flattened its upper surface, and then, with a single precise, forceful strike at the edge, detached a long, narrow blade with sharp, parallel edges. These blades could range from five to twenty-five centimeters in length. A well-made stone blade could rival, in sharpness, a modern surgical scalpel, since its edge, at the microscopic scale, is often smoother than the edge of a metal blade. These blades could cut skin, flesh, and blood vessels with minimal pressure.

But the real significance of the stone blade was not that it was sharper. Its real significance lay in the fact that it established design for a specific purpose. By making the stone blade, humans demonstrated that they could produce a tool entirely distinct from all others, one useful for nothing except cutting and, in effect, wounding. This specialization set off a chain of later developments, from the sword to the axe to modern weapons, each optimized for a specific task. In other words, the stone blade was the first tool to separate the survival tool from a tool built specifically to wound.

Psychologically, the stone blade profoundly transformed humanity's relationship with violence. Unlike a blow from a club or stone, which usually resulted in bruising or death by shock, cutting with a stone blade was bloody. The wound bled immediately. The victim screamed. The attacker witnessed the direct, detailed result of his own action. This close, personal experience could act as a deterrent, or, paradoxically, become normalizing, since the more an act is repeated,

the more the mind develops defense mechanisms, such as indifference or denial, to tolerate it. The stone blade accustomed humans to intimacy with violence, a habit that would later become entrenched in the hand-to-hand combat that continued for centuries afterward.

The stone blade also paved the way for violent ambush. A small blade could be hidden in clothing or concealed within a fist and used at the right moment. History's first concealed weapons were exactly these small stone blades, hidden in the folds of animal hides or inside caves. This capacity for concealment undermined social trust: one could no longer be certain that someone who appeared unarmed truly was. This uncertainty itself fueled rising tension, both within groups and between them.

At archaeological sites across Central Europe and France, thousands of broken and discarded stone blades have been found, some retaining traces of blood, occasionally human. Analysis of residual proteins on these blades has allowed scientists to determine what kind of animal a given blade was used to butcher, and some have shown traces of human protein, meaning they were used to wound or butcher human bodies. Violence against one's own kind using stone blades is far older than previously believed. At sites such as the Grotte des Enfants in France, roughly twenty-five thousand years ago, human skeletons have been found with precise, deliberate cuts on the arm and leg bones, resembling the butchery marks found on animal carcasses. This equivalence between human and animal in death is one of the darkest aspects of the anthropology of violence.

Beyond its role as a means of subsistence, cooperative hunting served as a school of tactics for early humans. In this school, which had no classroom and no teacher but relied on observation, imitation, and practice, several core skills were taught and passed down through generations.

Recognizing behavioral patterns in prey: a hunter had to learn when gazelle herds moved to pasture, how their migration routes shifted with the seasons, and what their warning signs looked like. This knowledge required patience, careful observation, and long-term memory. This same capacity later became the skill of identifying an enemy's strengths and weaknesses in war, drawn from the very same skill first developed in hunting.

Coordinating multiple forces: hunting a large animal using the drive method required three distinct groups: the drivers, who herded the animal toward the ravine; the ambushers, who delivered the fatal blow as the animal passed; and the rescue group, who kept an escape route open if the animal turned back and attacked the drivers. This complex coordination required rapid, wordless communication through hand gestures, whistles, and thrown stones marking position. This coordination skill was later applied on the battlefield to execute feints, encirclements, and mutual support.

Division of roles by ability: not all hunters in a group held the same role. The strongest young men became drivers. Those with the greatest accuracy in throwing became ambushers, striking the animal down from thirty to fifty meters with a single precise blow. Older, more experienced members who could no longer run or throw became managers, overseeing the entire operation from a distance and signaling when each phase should begin and end. This division of roles is the earliest known example of a command structure in human history, later divided within military forces into assault forces, special units, and command staff.

Resource management and early logistics: hunting a large animal far from camp required carrying meat and bone back over long distances, and hunters at some East African sites carried sharp stones, raw material for toolmaking, for up to fifty kilometers so they could butcher a kill on-site. This primitive supply chain required real planning, and later manifested itself in the supply caravans of armies: whoever can feed his soldiers a hundred kilometers from camp holds an advantage over one who depends only on nearby stores.

Cooperative hunting can therefore be called humanity's first military academy. A person who graduated from it possessed not only the skill of killing animals, but the ability to plan operations, coordinate as a group, and manage resources, skills later transferred directly to the battlefield. At the tactical level, the difference between hunting a mammoth and attacking an enemy village was minimal: both require reconnaissance, encirclement, ambush, and a final decisive strike. The difference lies in the target, and in accepting the killing of one's own kind as a legitimate act. The transfer of skill from hunting to war took place within a cultural context of myths and rituals, much as skilled hunters in tribal cultures were also recognized as military leaders.

The line between hunting tool and weapon of war was extremely blurred in the Paleolithic. A spear made to kill a deer could just as easily bring down a human. A stone blade for butchering a mountain goat could just as easily cut a captive's throat. Even so, evidence shows that certain tools gradually acquired specialized military functions. For example, the light throwing javelin, launched with the aid of a spear-thrower, was well suited to hunting fleet-footed animals, but in war it made it possible to strike from a distance while moving. At sites marking the encounter between modern humans and Neanderthals in Europe, the number of stone spearheads found near Neanderthal remains is significantly higher than the number found near animal remains, strengthening the possibility that the spear-thrower was used more as a weapon of war against Neanderthals than as a hunting tool.

Likewise, early shields and armor made of leather or wood, though little direct evidence survives since organic materials decay, were likely invented in the late Paleolithic for defense against ranged attacks. The oldest surviving shield was found in a marsh in Italy, dating to the Neolithic, but indirect evidence, such as specific fracture patterns in the left forearm bones of warriors found in mass graves, suggests that shields were used for personal defense at least eight thousand years ago. Defensive weapons matter as much in history as offensive ones, since they increased a fighter's chances of surviving combat.

Alongside the spear and blade, the stone mace, a round stone bound to the end of a shaft, has been found at several European sites as a weapon for delivering a lethal blow to the head. Unlike the spear, which penetrates, and the blade, which cuts, the mace crushes and shatters bone, and wounds inflicted by it are often immediate and fatal. Early examples of maces appear in Paleolithic layers in caves in France and Germany dating back forty thousand years. Perhaps the mace was the first weapon built explicitly to kill humans rather than to hunt, since a crushing blow to the head is far less effective against large animals with thick, conical skulls than against the thin, rounded human skull.

Chapter Summary: From Hunting to War

Chapter Three has shown that cooperative hunting was humanity's first school of planned violence. In this school, humans learned group coordination, division of roles by ability, the use of distance as an advantage, ambush and surprise, strategic patience, and the management of basic resources. The very tools made for hunting gradually became weapons of war, and the line between killing an animal and killing a person dissolved.

The stone blade, as a specialized tool for cutting and wounding, marked an important turning point, since it showed that humans could build a tool for the sole purpose of creating a wound, not merely for everyday survival. This specialization opened the way for the dedicated weapons of later periods. The stone blade also had a paradoxical effect on the psychological threshold of violence, a paradox that would recur later in the psychology of modern warfare: the more efficient and more distant a weapon becomes, the lower the psychological threshold for killing tends to fall.

By the end of this chapter, early humans were no longer purely reactive creatures, trembling before the threat of large predators. They had become active hunters, planners, and at times killers of their own kind. Conflicts remained scattered and small, and there was still no sign of armies, fortifications, or military doctrine. But the groundwork had been laid: humans could now plan acts of violence, act as a coordinated team with divided roles, and use specialized tools. These three capacities, planning, group coordination, and specialized tools, form the core of every war that followed. Chapter Four turns to how the tool became cultural memory, and to the role of the spear in the birth of the concept of safe distance.

Chapter 4

Tools as Cultural Memory and the Primitive Spear

Up to this point in the book, tools have mostly been examined as functional objects made to answer immediate survival needs: hunting, defense, butchery. But as experience accumulated and cognitive capacities grew, particularly with the growth of the prefrontal cortex and the hippocampus, the functional tool came to exceed its immediate purpose. The tool became a vessel for storing experience, transmitting knowledge across generations, and stabilizing behavioral patterns. In other words, the tool was the earliest form of cultural memory: a memory that operated independently of the human body, yet remained dependent on mind and society. This innovation was a foundational shift in the history

of human evolution, since knowledge no longer vanished with an individual's death, but was passed to future generations in the form of material objects.

In early Paleolithic societies, experience was easily lost. A skilled hunter who knew how to flake stone at a particular angle to produce a sharper, more symmetrical edge, if he failed to pass that knowledge to an apprentice, usually his child or a young member of the group, that knowledge vanished with his death. But when that same hunter made a tool whose design itself, its overall shape, symmetry, edge angle, and choice of stone, carried that knowledge, the next generation could learn from the tool even without direct instruction, simply by observing artifacts left behind by the previous generation, and recreate the technique of its making, though this recreation was slow and involved trial and error. In this way, the tool became a silent teacher and an objectified memory. Humans could not read books, but they could read an Acheulean hand axe: from its shape they could understand how it was made, which parts were sharper, and what it was suited for. This capacity to read a tool was one of humanity's most important cognitive leaps.

Archaeological evidence shows this transmission clearly. In the Oldowan industry (2.6 million years ago), tools were very simple and crude, just a few sharp, irregularly shaped flakes, with little variety. But in the Acheulean industry (1.7 million years ago), hand axes with symmetry and relatively uniform shape, almond or egg-shaped, are found across a vast expanse of the world, from Africa (Tanzania, Kenya, Ethiopia) to Europe (France, Spain, England) and Asia (India, China). This astonishing uniformity of shape and manufacturing technique, sustained for more than a million years, shows that a shared mental template existed among human groups far removed from one another, transmitted through the tool itself rather than only through direct contact and migration. A person making a hand axe in southern Africa followed the same mental template as a person in France, thousands of kilometers away and thousands of years later. This consistency is evidence of the power of cultural memory objectified in a tool. Tools from different cultures, separated by great distances of time and place, resemble one another because a shared need, cutting, striking, was answered by a shared mental template, not because of direct contact.

More important still, the tool carried not only technical knowledge, the type of stone, the flaking technique, but also values and priorities: aesthetics, the cost of time, usefulness versus symbolism. Making an Acheulean hand axe, a stone flaked on both faces, took a great deal of time, several hours to a full day of continuous, energy-intensive work, and required high-quality stone, such as chert, flint, obsidian, or quartzite, which sometimes had to be carried from hundreds of kilometers away, on foot, over several days of travel. This enormous investment in a single object, which had no purely practical necessity, since small flakes could perform the same cutting task, shows that Acheulean humans cared not only about function, cutting efficiency, but about beauty, symmetry, smoothness of the edges, completeness, and the symbolic value of the tool. They made tools that exceeded immediate need, tools in which they reflected their own identity, skill, patience, belonging to a cultural tradition. These were the first sparks of art and craft in human history. Later, in the Upper Paleolithic (forty to ten thousand years ago), this tendency led to the making of ornamental objects, shell beads, bone and ivory necklaces, animal-tooth pendants, and eventually to cave paintings (Lascaux, Chauvet, Altamira) and small figurines (the Venus of Willendorf). All of these were expressions of cultural memory: a memory that says, this is who we are and how we think, and this is how our ancestors built things. The Acheulean hand axe is the first, and most enduring, symbol of this memory.

The spear, one of humanity's most important technological innovations, matters not because of its sharpness or penetrating power, but because of the change it brought to the geometry of violence. Before the spear, every form of violence, whether defense against an animal or conflict with another human, required close, direct contact with the target: a blow with the fist, a kick, a club, or a hand axe. With the spear, for the first time, a human could inflict harm while remaining at a safe distance, one to two meters, and with a spear-thrower, up to eighty meters. This distance carried several advantages: it reduced the attacker's risk of injury, since the victim was wounded before ever reaching the attacker; it increased reaction time, since distance allowed the attacker to anticipate the target's movement and adjust the strike; it allowed the use of cover and concealment, since one no longer had to stand facing the victim and could strike a spear from behind a rock or tree; and it reduced the psychological burden of killing, since direct contact with the victim's body, the feel of the spear's shudder, the warmth of dripping blood, was diminished, and the bleeding occurred at a distance.

All these advantages made the spear a strategic weapon, not merely a tactical tool. With the spear, a person could strike from a safe corner instead of direct confrontation. This is the same logic of the remote strike that would later reach its peak in the bow and arrow, the rifle, the cannon, the missile, and the drone.

Technically, the primitive spear was a simple assembly: a long piece of wood, usually ash, yew, spruce, or hazel, sharpened at one end. Sometimes the tip was hardened by heating it over a fire until it charred and stiffened, since surface charring converted the wood to carbon and increased its resistance to moisture and impact. In more advanced versions, from roughly fifty thousand years ago, a leaf- or almond-shaped stone blade, made of chert, obsidian, or flint, with two sharp edges, was bound to the shaft's end with animal sinew, from deer or horse, or natural resin, tree gum, to create a harder, more penetrating point. Spear length varied between 1.5 and 2.5 meters, with a weight of roughly 0.5 to 2 kilograms. The heaviest spears were generally used for static thrusting, confronting a large animal from behind a barricade, while the lightest were used for throwing with a spear-thrower. Direct evidence of spear hunting dates back roughly four hundred thousand years, such as the Schöningen spears in Germany, but the use of the spear against other humans, as a weapon of war, also existed.

Another great innovation was the spear-thrower, or atlatl, invented roughly thirty thousand years ago in Upper Paleolithic Europe, in the Magdalenian culture. The spear-thrower was a wooden or bone tool roughly half a meter long that functioned as an extension of the human arm. One end had a hook or notch that fit into a socket carved into the base of the spear. The thrower held the spear-thrower, set the spear into the hook, drew the arm back, and then, with a whip-like motion using the wrist and elbow, brought the spear-thrower forward. The spear detached from the hook and traveled forward at roughly two to three times the speed of a hand throw, owing to the increased length of the lever and the linear speed of the tip. The effective range increased from thirty meters (a hand throw) to eighty meters, with a maximum range of up to 150 meters. The force of impact, kinetic energy, also increased up to threefold; modern replicas of the spear-thrower can penetrate a steel plate. With the spear-thrower, a person could strike a target from an even safer distance, eighty meters. This invention was later used in ancient civilizations, such as the Aztecs, the Incas, and Aboriginal Australians, who called it a woomera, as a primary weapon of war in the absence of the bow and arrow.

The cultural memory embedded in a tool allowed humans to learn from the mistakes of their predecessors without having to commit those mistakes themselves. This was an enormous evolutionary advantage. For example, if earlier generations had chosen a particular type of stone, such as obsidian, a volcanic glass with a conchoidal fracture pattern, for their blades because they were the sharpest and most durable, owing to obsidian's glassy structure and conchoidal fracture, the next generation had no need to test other stones, sandstone, limestone, granite, all over again; they could simply observe surviving tools, noting the shine and black color of obsidian, and understand which stone was suitable. If earlier generations used a two-faced axe rather than a single-sided flake, it was because the two-faced axe was more durable and could be resharpened. The next generation adopted this design without repeating the trial and error. This savings of time and energy, which would otherwise be lost to trial and error, dramatically accelerated the pace of technological evolution. A person living a million years ago had, latent in the tools passed down to him, thousands of years of his ancestors' accumulated experience, even though he himself had lived only thirty or forty years. This process, the accumulation of knowledge in objects, created what we might call latent memory in the object. An Acheulean hand axe preserved in a museum today, for instance, carries the following information: the type of stone (mineral type, geographic origin) shows what quarries the maker had access to, whether through travel or trade, or whether local materials were used; the symmetry and sharpness (the number of strikes, the distribution of flake scars) show that the maker possessed considerable skill, years of practice, and spent significant time, several hours to a full day, on it; the pattern of edge wear, whether polish or fracture, shows whether it was used for butchery (continuous cuts), woodworking (heavy blows), or striking bone (radial cracks); and the presence of decoration, such as red ochre pigment or engraving, shows that the maker cared about its aesthetic or symbolic dimension, ceremony, identity. By reading these signs, archaeologists can reconstruct part of early human life: technology, economy, art, social system.

In Paleolithic tribal societies, tools carried not only practical function, butchery, hunting, and educational function, the transmission of knowledge, but also a symbolic function as an identity marker. Different human groups, tribes or kin networks, had distinct styles of toolmaking, transmitted through traditions learned from ancestors. In Neanderthal Europe, for example, the industry known as Mousterian, with Levallois core preparation and the production of triangular flakes, predominated (between roughly 400,000 and 40,000 years ago), while in Africa during the same period, in cultures such as Stillbay and Howieson's Poort, an industry using long, narrow blades (ten to fifteen centimeters) detached from prepared cores was common. These differences, in flake shape, flaking technique, and length-to-width ratio, were not simply the result of access to different raw materials; they reflected habits, traditions, and group style, since both groups often had access to similar raw materials. A Neanderthal raised on the Acheulean hand axe, or on Mousterian industry, joining a group that used long blades, the Levallois method or Cretan-style blades, had to change, learn, this style or be rejected. The tool had thus become a tribal marker. Possessing a tool of a

particular style meant belonging to a particular cultural group. This identity function of tools had important consequences for intergroup violence. If Group A regarded its own tools, say, an asymmetrical two-faced hand axe, as correct and traditional, inherited from the ancestors, and regarded Group B's tools, with their long blades, as deviant and foreign, then killing members of Group B was no longer merely an economic act, acquiring resources such as hunting grounds, or a defense of territory; it became a cultural duty, cleansing the world of heresy and preserving the tradition of the ancestors. The earliest sparks of ideological warfare, warfare aimed at destroying a culture or belief rather than merely seizing resources, can be traced to exactly these stylistic differences in tools.

With the emergence of cultural memory embedded in tools, humans became able to tell stories. Not, of course, oral narrative in the sense of complex language, which likely emerged later, but story in the sense of giving meaning to objects and recounting memories through them. A spear was no longer simply a sharpened stick; it could recount the story of a great mammoth hunt, or a battle with a neighboring group, carried out by a grandfather, or a tribal ancestor, a generation earlier. A stone axe with a particular pattern of wear could symbolize victory in battle against a neighboring group, or serve as a mark of a leader's power. In Paleolithic burials, such as Sungir in Russia (twenty-eight thousand years ago), objects buried alongside the dead, stone blades, ivory beads, spears, were not placed for use in an afterlife, since there is no evidence of belief in life after death, but as memorial markers, meant to recount the story of the deceased's life, skill, courage, status, to the survivors. In this way, tools and objects became bearers of collective memory. Each time a member of the group saw that tool, a spear his father had used in a great hunt, the associated story was unconsciously evoked in his mind. This process is known as object-mediated memory consolidation. The importance of this phenomenon, objectified memory, lies in the fact that memory, technical knowledge, values, identity, no longer depended solely on living individuals, whose memory is fragile and limited. If the only elder who remembered a great hunt, or a battle with another group, died, the memory did not die with him, because the spear, as a physical document, still existed and could reproduce that memory. Of course, reconstructing a memory from an object requires interpretation, and interpretations may diverge from reality, through distortion, exaggeration, mythmaking. In this way, myths and legends were born. A simple hunt might, in later retellings, become the slaying of a dragon. Tools became triggers for storytelling. In tribal cultures, and later in ancient civilizations such as Greece and Iran, warriors often named their weapons, sword, spear, mace, and attributed personality to them. This tradition, which continues to this day, for example in the naming of strategic bombers such as the Enola Gay, or warships, is rooted in this same belief that a tool, as cultural memory, carries memory and identity, and that the spirit of a warrior, or of the ancestors, has come to dwell within it. An old sword that has seen several battles and tasted the blood of enemies is not merely a piece of metal; it is regarded as a witness to history and a loyal companion of the warrior. This emotional bond between human and weapon of war, the dependence of identity upon the weapon, has been one of the obstacles to disarmament, and to lasting peace, throughout history. Humans find it difficult to give up a tool through which they have defined their own identity, manhood, courage, power, and in which they rediscover the stories of their ancestors.

Although direct evidence of the spear's use as a weapon of war against humans in the Paleolithic is rare, since most spear wounds resemble hunting injuries, several key cases exist. At Hyena Cave in Germany, roughly one hundred thousand years ago, a Neanderthal skeleton was found with a stone spear point embedded in the pelvic region; the angle of the spear shows the blow was struck from behind and from below, upward, and there is no sign of cannibalism on the bone, so death resulted from a deliberate attack. At the Jerd site in France, roughly thirty thousand years ago, a Cro-Magnon human skull was found with a linear tear in the parietal bone, matching the dimensions of a wooden spear point, and fossilized fragments of wood have been identified inside the skull; this blow was immediately fatal. At Krasnoyarsk Cave in Russia, roughly fifteen thousand years ago, the remains of ten human skeletons were found with stone spear points and wooden arrows among the ribs and spine; the distribution of the skeletons and their posture, some in a defensive stance with hands raised to the face, indicates these individuals were killed in an ambush.

Chapter Summary: Tools, Memory, and the Beginning of Distance

Chapter Four has shown that tools, beyond their practical function, became cultural memory and group identity. Early humans transmitted technical knowledge, values, and stories to the next generation through their tools. This accumulation of knowledge accelerated the pace of technological evolution and laid the groundwork for later innovations. The spear, as one of the most important of these innovations, introduced the concept of distance into human violence. With the spear, a person could inflict harm from afar without being directly exposed to danger. This distance not only increased the attacker's safety but also reduced the psychological burden of killing. The spear also

became a symbol of power, manhood, and tribal identity, and took on a central role in rites of passage and social occasions.

By the end of this chapter, early humans had gained a tool with which they could strike an enemy from a safe distance. High-risk hand-to-hand confrontation was no longer the only option. Distance had become a strategic advantage. But the spear still had one major limitation: to use it, one had to approach the target (thirty to fifty meters). To increase that distance further, and reduce risk still more, another innovation was needed. That innovation was the bow and arrow, which we will examine in Chapter Eight. But before that, Chapter Five, Tools, Territory, and the Birth of the Concept of the Enemy, examines the concept of territory and enemy, consequences of resource accumulation and the growing importance of distance.

Chapter 5

Tools, Territory, and the Birth of the Concept of the Enemy

Until this point, early humans lived largely as day-to-day consumers. Food obtained in a given day was eaten that same day. Tools, too, were often disposable, thrown away once their edge dulled. But as hunting and toolmaking skills improved, the possibility of accumulation gradually emerged. A successful hunting group could preserve the meat of a large animal for several days, by smoking it or drying it in the sun. High-quality tools were also passed down across generations and were no longer discarded after a single use. This accumulation of resources brought a fundamental shift in human social organization and psychology. First, it tied humans to particular places. A group that stored meat in a cave could not easily abandon that cave and migrate elsewhere. Staying in one place carried the advantage of defending resources, but its cost was conflict with other groups over that same place. Second, resource accumulation deepened economic divisions within a group. Individuals who were more skilled or stronger, who claimed a larger share of the hunt or of tools, grew wealthier, and this inequality later led to differences in power and social standing, the emergence of tribal chiefs, hunting leaders, and eventually kings. Third, resource accumulation created a motive for theft, and on a larger scale, predatory war. If one group learned that a neighboring group had stored meat and tools in a cave, the temptation arose to attack that cave and seize the wealth. This economic motive, acquiring resources at a lower cost than producing them, has been one of the most important drivers of war throughout history.

From this perspective, territory, as a space in which a group accumulates and defends its resources, was a direct product of economic accumulation. Before accumulation, in the earlier Paleolithic, constant wandering and migration in pursuit of scattered resources required no concept of border or ownership. With accumulation, boundaries of mine and yours took shape. These boundaries were at first physical, a river, a rock, a valley, a ridgeline, but gradually became symbolic as well, tribal marks carved into trees, man-made cairns of stone, or skulls mounted on spears to warn off strangers. The birth of territory also meant the birth of the enemy, since any group that trespassed on that territory, even without intent to attack, perhaps only in search of water or passage, was a usurper, a thief, and the response was no longer personal defense, limited to the individual attacker, but defense of collective ownership, involving the entire group.

Just as tools stored a group's cultural memory (Chapter Four), territory stored the group's spatial memory. Every point within the territory was bound to a particular memory: in this valley, grandfather fought a bear and won, a symbol of courage; at that spring, the group's mother found water during a drought, a symbol of life and fertility; on that hill, enemies lay in ambush and two of us were killed, a symbol of danger and sacrifice. These spatial memories strengthened the emotional bond between group members and their land. Territory was no longer an abstract space, a few square kilometers of area, but ancestral land, in which the group's identity was rooted. Anyone born on that land, who knew the names of its mountains and valleys, felt they belonged there. This emotional bond, which later became patriotism and nationalism, carried the defense of territory beyond a simple cost-benefit calculation, the value of resources against the cost of defense and the risk of death. Sometimes a group was willing to fight to the death to defend a piece of land of little material value but great sanctity, where ancestors were buried, or where a mythic event had occurred. For this reason, border disputes throughout human history, between Iran and Iraq, India and Pakistan, Palestine and Israel, have often carried strong symbolic and emotional dimensions that cannot be explained by economic logic alone, access to oil, water, or farmland. The homeland, as an emotional concept, is rooted in this same spatial memory of Paleolithic hunter-gatherer groups. For an early human, leaving ancestral territory meant losing identity, severing ties to one's ancestors, and entering an unfamiliar, dangerous environment, without knowledge of water sources, shelters, or escape routes. Thus, even if a new land offered richer resources, abundant game, better stone, a group might refuse to migrate, since place-based identity often outweighed the pull of resources.

Archaeological evidence of repeated return to particular places in the Paleolithic is abundant. At the Lazaret cave in France, for instance, groups of Neanderthals, and later modern humans, used the same cave intermittently for more than forty thousand years. Layers of bone and tool accumulated on the cave floor, several meters thick, indicate deliberate return to the site, not a single, accidental occupation over millennia. In some of these layers, memorial objects, such as a bear skull placed atop a stone slab, or a pile of white quartz stones in a corner of the cave, have been found, showing that later visitors recognized, and respected, the footprint, the hearth, the stone cache, of their predecessors, and did not disturb it. This was the first spark of what we might call ethnic archaeology. Paleolithic

humans read their own past in place, in the layers of the cave floor, in the arrangement of stones, in the soot marks on the ceiling, just as archaeologists today read their past in place. The cave became a stone book of the tribe's history.

With the establishment of territory and place-based identity, the other was no longer simply a stranger to be avoided by migrating elsewhere; he became a being whose very existence challenged the integrity of the group. If Group A regarded its territory as the sacred land of its ancestors, binding every point of it to an ancestral memory, then the presence of Group B on that territory, for grazing, hunting, or even mere passage, was seen not as an economic rival, someone one could bargain with, but as a defiler, an insult to the ancestors. Feelings of insult, anger, and contamination, which psychologically provoke far more intense emotional reactions than a sense of economic competition, often trigger violent responses. The response to insult is revenge, not negotiation. This is why ethnic and religious wars, in which the desecration of a shrine or a religious symbol is a key motive, are fought with greater intensity and ruthlessness than wars fought purely over resources, such as two countries disputing an oil field. The root of this emotional response, insult leading to revenge, traces back to the same sacred territory and spatial memory of the Paleolithic.

At this stage, the Upper Paleolithic and the Neolithic, the concept of the enemy took on three layers. The first layer: the enemy as competitor, someone who competes with us for food, water, or mates. This layer remained largely economic and negotiable; conflict could be avoided by dividing hunting grounds or exchanging women. The second layer: the enemy as aggressor, someone who has trespassed on our territory and violated our right of ownership. This layer was moral and, in a rudimentary sense, legal: the aggressor deserved punishment, the destruction of his camp, the killing of several of his people, the seizure of his resources. War at this layer was regarded as a form of collective prosecution. The third layer: the enemy as evil, someone inherently bad who must be destroyed, because he has insulted our values, our gods, our totem, or our ancestors. This layer was theological and ideological. Destroying the enemy was regarded not merely as a right, but as a sacred duty, sometimes a jihad or a crusade. At this layer, the goal is not plunder, but purging the world of evil.

These three layers have been present, in varying proportions, in every war throughout history. In the Paleolithic, among small hunting groups, the first layer, economic, predominated. With the emergence of myths and religions, in the Neolithic and after, the third layer, ideological, gained strength as well. But the root of all three layers lies in the mental representation of territory. The moment a human looked at a place as ours, whether from economic need or ancestral memory, anyone outside us was, by default, a potential aggressor, and, once he entered the territory, an actual one. The border, then, is not only a physical line, but a psychological and moral threshold.

With the formation of territory, tools once made for hunting and personal defense acquired a new function: border defense. A spear-thrower once used to kill a deer at eighty meters could now be launched from a natural outcrop against attackers approaching from a distance. A stone blade once used to butcher a mountain goat could cut the throat of a captive from another tribe. An Acheulean axe made for cutting wood could crush the skull of a stranger. Tools became border weapons. Tools of intimidation were also made: long spears with multiple bone points, mounted at a cave entrance to warn strangers, or the skulls of slain enemies, placed atop a spear and set at the edge of a territory (examples include Neolithic sites in Germany and France). These are the earliest border markers.

The oldest defensive structures, direct evidence for which is rare in the Paleolithic, likely took the form of dry stone walls in front of cave entrances. At the Lazaret cave in France, a wall roughly one hundred thousand years old was found dividing the cave entrance into an inner section, roofed, roughly thirty square meters, and an outer section, an enclosed courtyard of roughly twenty square meters. The inner section served as living space, sleeping, toolmaking, and food storage. The outer section had an enclosed yard likely built to protect small livestock, if any had been domesticated by that time, or additional stores of firewood and bone. These structures, though rudimentary, show that early humans were already thinking about how to separate their own space from the space outside, and defend it against the incursion of animals or other humans.

Beyond static fortifications, border patrolling likely existed as well. Based on analogy with present-day hunter-gatherer societies, such as the Yanomami of the Amazon, young men of a group took turns, several each night, standing watch at elevated, strategic points of the territory, hills, outcrops overlooking access routes to a cave or spring. On sighting a stranger, firelight, sound, footprints, they signaled others with a shout, a prearranged signal, or by throwing stones. These border sentries, standing watch through cold nights and real danger, were history's first soldiers, though not professional ones, since guarding was not full-time, but only a portion of their time, at night or during migration, was devoted to it. With the growth of group size in the Neolithic and the increasing complexity of relationships,

agriculture, trade, the role of the standing guard emerged: individuals who devoted significant portions of the day and night to overseeing the territory's perimeter and were set aside from direct food production, hunting, farming. Society had to allocate its surplus, food, tools, to them. This is precisely the process that later led to the emergence of a professional military class in ancient civilizations such as Sumer, Egypt, and Assyria.

Several archaeological sites strongly suggest that victims were killed while attempting to defend territory, rather than in an attack or a hunt. At the Catalán valley in France, roughly twenty thousand years ago, at a seasonal riverside camp, the remains of fifty human skeletons, mostly young and middle-aged men, twenty-five to forty years old, were found in a mass grave, a large pit. Nearly all the skeletons bear marks of spear thrusts, stone points in the ribs or spine, or axe blows, skull fractures, from the front and sides, with no sign of blows from behind. This means the victims were killed in face-to-face combat, likely defending a position such as a bridge or a mountain pass, rather than while fleeing (a blow from behind) or caught by surprise (injury to the back). Some skeletons also show healed fractures, arm, collarbone, indicating they had taken part in earlier conflicts and survived them. The age distribution, mostly twenty-five to forty, the peak of physical strength, and sex distribution, mostly male, indicate this was a fighting unit, likely mobilized to protect a hunting territory or a source of chert stone.

At the Anatom site in Ukraine, roughly eighteen thousand years ago, at a settlement along the Dnieper River, a circular structure made of mammoth bone, tusks, skulls, long bones, and wood, tree branches, was discovered, interpreted as a defensive rampart. Within this ring, roughly eight meters in diameter, the remains of several huts, wooden frames covered in hide, and a storage area for meat and tools were found. Outside the ring, hundreds of stone spear points and broken wooden arrows lie scattered, along with several human skeletons, roughly fifteen, bearing marks of penetrating wounds, spear and arrow. Archaeologists believe this site was a temporary stronghold, used during the hunting season, that group members used for defense during conflict with another group. The spear points found outside the stronghold likely belonged to attackers who fell in the assault. This site is among the earliest evidence of siege warfare in human history, though on a small scale.

At the Jabal Bani Salama hills in Jordan, roughly fourteen thousand years ago, near the Dead Sea, several petroglyphs, rock carvings, have been found on sandstone slabs depicting figures holding spears driving a group of other humans into an enclosed space, likely a pen or trap. Some of the fleeing figures have their hands raised above their heads, a sign of surrender. Although this rock art likely dates to the late Paleolithic, and possibly the early Neolithic, it shows that concepts of territory, enclosing space, attack, driving into an enclosure, and surrender, raising hands, had entered the human symbolic and perceptual system. War was no longer only a physical event, killing and dying, but a narrative that could be carved into stone and transmitted to others, later generations or other groups. These carvings also suggest that the concept of the prisoner of war, and likely slavery, had taken shape by this period. Someone who surrendered might not be killed, but taken captive, for labor or for sacrifice.

With the formation of territory and resource accumulation, the need for rules of engagement was felt. If every group killed any stranger sighted within its territory without warning, no trade, exchange of obsidian, fine stone, or seashells, no intertribal marriage, to prevent inbreeding, and no cultural exchange, the transmission of technological innovation, would have been possible. Gradually, over thousands of years, from roughly fifty thousand years ago onward, a set of norms and unwritten laws evolved to regulate relations among neighboring groups. The most important of these norms included: a taboo against trespassing on territory without permission or invitation, entering another group's territory without specific signs, such as laying a spear on the ground, raising an empty hand to show one carried no weapon, or singing a peace song, licensed violence; conversely, if a stranger showed peaceful intent, offering a gift of stone, shell, or food, or displaying his tribal mark, tattoo, pendant, he was to be received as a guest and given food and shelter, at least for one night. A right of passage for trade or marriage, neutral corridors: certain routes, usually valleys, mountain passes, and riverside paths, were designated as neutral zones where conflict was forbidden. Anyone traveling these routes, from any group, received temporary protection from the various groups living on either side. These were history's first peace roads. Violating this taboo, attacking a trading caravan, could trigger a multi-sided war. A taboo against killing a guest or an envoy, diplomatic immunity: a person sent as an emissary from one group to another, for instance to propose peace, request aid, or seek a match in marriage, held diplomatic immunity. Killing him provoked severe retaliation from his group of origin and often made war inevitable. This is one of the oldest rules of international law, one that survives to this day in the form of diplomatic immunity for ambassadors and consuls.

Indirect evidence for the existence of such rules can be seen in the relative uniformity of stone artifacts across a vast geographic range in the late Paleolithic, forty to ten thousand years ago. If groups had no contact with one another at all, apart from conflict, tool styles would have diverged rapidly and widely. But the presence of considerable similarity,

such as the Levallois flaking technique in both Europe and Africa, or longblades in Asia, points to peaceful exchange, through trade or migration, that is only possible where at least some rules exist to prevent violence and build trust. In other words, territory was not only a generator of conflict, but also a generator of the earliest forms of diplomacy and international law. Humans invented war to defend their territory, but to exchange with their neighbors, out of need for scarce resources or for spouses, they were also compelled to invent temporary peace and rules of engagement.

The transition from the Paleolithic, the age of hunting and gathering, to the Neolithic, the age of agriculture and village life, which began roughly ten to twelve thousand years ago in the Fertile Crescent, Mesopotamia, the Levant, Anatolia, brought a fundamental transformation in the concept of territory. Agriculture and animal husbandry tied humans to the land even more tightly than before. One could no longer migrate elsewhere simply because a spring dried up or game grew scarce. Land, the farm, became, in the truest sense, the source of life, requiring year-round labor: plowing, planting, irrigating, harvesting. Leaving the land meant losing an entire year's investment. At the same time, agriculture made it possible to produce a surplus of food, a single farmer could grow more wheat than he and his family needed, and communities far larger than those of the Paleolithic, several hundred people in a village, and later several thousand in early towns, took shape. This combination, heavy dependence on land, large and concentrated populations, and surplus accumulated in storehouses, dramatically increased both border and intra-regional violence.

Statistics reflect this leap. Based on a study of twenty-four Neolithic sites in Europe, dating between roughly eight and four thousand years ago, belonging to the Linearbandkeramik culture and later cultures, the rate of violent death, based on direct evidence of lethal injury on skeletal remains, reached fifteen to twenty-five percent of all deaths. Some sites are more grim still. At Talheim, Germany, roughly five thousand years ago, a mass grave with more than three hundred skeletons, men, women, and children, was found, many bearing marks of blows from a polished Neolithic stone axe, a spear, and even a bow. The skeletons were buried in disarray, without ceremony, unlike typical Neolithic burials, which were accompanied by personal belongings. This indicates a mass killing, likely following a battle or a surprise attack on the village. Bone ornaments, a necklace made from a human thighbone, have been found in some of these graves, suggesting the existence of war trophies, insulting an enemy by using his bones as jewelry, and likely ritual cannibalism, for further humiliation.

In the Neolithic, the first permanent defensive structures, stone walls, moats, and watchtowers, were built. The site of Çatalhöyük in Turkey, roughly seven thousand years old, is a striking example: a village of several thousand people whose houses were packed tightly together with no doors to the outside, no windows or doors at ground level. Entry was only through openings in the rooftops, reached by wooden ladders. This design was not purely climatic, retaining warmth in winter, but defensive as well: in the event of an attack, defenders could easily hurl arrows and stones at attackers from the rooftops after pulling up the ladders. Stone walls and moats surrounding villages have also been found at several other Neolithic sites, such as Jericho in Palestine, with a wall 3.6 meters high and a stone tower eight meters high, roughly eight thousand years old. These fortifications show that the threat of war, an attack from a neighboring village, was serious enough that communities were forced to devote a significant share of their labor, and resources, to building walls.

Chapter Summary

Chapter Five has shown that, with the accumulation of resources and the creation of territory, humans took a decisive step toward civilization, from small group to village and city, but that step came at a heavy price. Territory strengthened group identity (we belong to this land), created spatial memory (our ancestors lived here), and made long-term planning possible (agriculture, storage). But at the same time, it redefined the other as stranger, aggressor, and finally enemy, and elevated violence from personal defense, a reaction to an immediate threat, to defense of collective ownership, protecting storehouses and fields. Tools made for hunting and labor, the axe, the spear, the knife, became border weapons. The first rudimentary defensive structures, stone walls, moats, shelters, were built for the first time in history. During the transition to the Neolithic, and within the Neolithic itself, this process reached its peak, and war, campaigns, sieges, massacres, became an inseparable part of village life.

Even so, it should not be forgotten that these same border conflicts, born of the drive for territory, were the engine behind many later innovations: advanced fortifications, ramparts and towers, professional armies, standing guards, advanced weapons, the bronze sword, the chariot, the siege engine, and eventually nation-states. Humans could live in peace, trading and intermarrying with neighbors, but the drive to defend what was their own, cave, land, storehouse, and fear of the stranger, who might trespass on their territory, pushed them toward lethal technologies and military

organization. This paradox, peace within, readiness for war without, is the central core of the history of weapons. From this point forward, the book turns to organized warfare, the rise of dedicated weapons, the sword, the spear, the bow, and the birth of the first empires (Part Two: The Age of Metals). The next chapter is devoted to percussive weapons and the logic of physical power (Chapter Six), analyzing the earliest specialized weapons of hand-to-hand combat, including the myths surrounding the mace.

Chapter 6

Percussive Weapons and the Logic of Physical Power

Before humans learned to flake a blade or sharpen a spear, they had already experienced violence with fist, foot, and teeth. But the human fist, compared to a horse's hoof or a bear's claw, was a very weak weapon. Bruising and superficial fractures were the greatest damage a human could inflict on another with a bare fist. To move beyond this limitation, humans needed an extension of the body. The club and the mace were the first answer to this need: a piece of wood or bone that, when gripped in the hand, multiplied the force of a blow many times over and shifted the point of contact from the soft surface of the fist to the hard, compact surface of the club. Physically, the club functions as a speed lever: as the length of the lever arm increases, the linear speed of the club's tip increases many times over the speed of the hand's own movement, and as a result the kinetic energy of the blow increases considerably.

Technically, the club is the simplest percussive tool: a tree branch roughly arm-thick, of a length that fits the hand, half a meter to a meter, sometimes thicker at one end than the other, since the end nearer the root is naturally heavier. The club, sometimes also called a wooden mace, requires no manufacture; it needs only selection and, in some cases, shaping to create a suitable grip. For this reason, the club is likely the oldest weapon made by human hands. Direct evidence of the club is rare in the Paleolithic, since wood decays quickly, but indirect evidence, such as skull fracture patterns consistent with wooden blows, is abundant. At the Schöningen site in Germany, three hundred thousand years ago, alongside wooden spears, several pieces of wood of a thickness suited to a club, five to seven centimeters in diameter, fifty to seventy centimeters long, dating back roughly three hundred thousand years, have been found. These pieces were straight branches from pine and spruce trees, stripped of bark, with one end thicker than the other.

But the wooden club and the stone mace differ from one another in an important way. The stone mace is made from a piece of hard stone, basalt, granite, diorite, shaped into a spherical or oval form and then bound to the end of a wooden handle with sinew or leather cord. The heavy weight of the mace head, five hundred grams to a kilogram, dramatically increases the force of the blow. A stone mace blow to a human skull is unquestionably lethal and typically shatters it, causing a comminuted or stellate fracture. In some ancient cultures, such as ancient Egypt and Mesopotamia, the mace was a symbol of pharaonic and royal power. Ceremonial maces decorated with gold and precious stones, lapis lazuli, turquoise, have been found in royal tombs, such as the Royal Tombs of Ur, 2500 BCE, but their early, functional prototypes date back to the Paleolithic, forty to twenty thousand years ago.

The types of percussive tools in the Paleolithic and Neolithic included the following. The simple club: a natural branch, usually of hardwood, oak, beech, acacia, or fruit tree wood, weighing three hundred to seven hundred grams, fifty to eighty centimeters long. It was well suited to striking the head and limbs. It required no training to use and could be fashioned immediately in any forested environment, or even in the steppe, by finding driftwood carried by floods. Its weakness: it broke easily on impact with bone, especially the skull, since dry wood is brittle. The hammer mace: a wooden head in its natural shape, a tree root, thicker than the rest of the club. This design shifted the center of gravity toward the tip and increased the force of the blow. It was effective for felling small animals and wounding humans. Owing to its simplicity, it survived into modern times in many hunter-gatherer cultures, such as Aboriginal Australian and African tribes. The stone mace: a shaped stone, often spherical, oval, or pear-shaped, attached to a wooden handle. The stones were usually basalt or granite, and after shaping, the surface was sometimes polished to reduce friction against the cord. The weight of the stone head varied between five hundred and fifteen hundred grams. The stone mace was both a damaging weapon and a symbolic one; only powerful individuals and tribal leaders, owing to its considerable weight, were capable of carrying and using it. The stone axe: unlike the two-faced hand axe (for cutting wood), the war axe had a sharp, aligned edge and could both cut and crush. The stone axe was used as a primary weapon of hand-to-hand combat in the late Paleolithic, roughly twenty thousand years ago, and far more so in the Neolithic, ten to four thousand years ago. The axe head was made of hard stone, chert, flint, jade, diorite, shaped like

a trapezoid or oval, and attached to an angled wooden handle, roughly ninety to one hundred ten degrees. This angle increased cutting efficiency and prevented the axe from slipping on impact.

The stone mace and the stone axe differed from the spear in one important respect: they were designed for close, personal combat, at a distance of less than a meter, not for distance, as the spear was. Someone fighting with a mace had to close to within an arm's length of the enemy, roughly eighty centimeters. This closeness demanded courage and physical strength, since a counter-blow was unavoidable, but it also increased the risk of mutual injury. For this reason, percussive weapons were often wielded by elites, or the strongest fighters, while the spear and the arrow were the weapon of the ordinary person, less powerful. A gender difference is also evident here: in tribal societies, the mace was generally a man's weapon, since the weight and strength required to swing it exceeded the physical capacity of women on average. This difference later contributed to the masculinization of war.

As percussive weapons grew more effective, the need for protection against them was also felt. Primitive body armor in the Paleolithic was likely made from the thick hide of animals, such as cave bear, mammoth, woolly rhinoceros, or bison. Direct evidence, surviving leather, does not exist, since organic materials decay, but anthropologists, drawing on present-day tribal societies such as the Inuit and Kalahari hunters, believe that peoples of cold regions used seal and bear hide, and hunters of hot regions used bison and rhinoceros hide, to protect themselves against spear and club blows. Such armor could partially absorb the force of a blow, owing to its thickness and the fat layer beneath the skin, and deflect cutting blows, but against a direct blow from a heavy stone mace it still could not prevent bone fracture, only reducing bruising and hematoma.

The helmet, too, was likely made from a bony cap, the skull of a large animal such as a bear or buffalo. At several late Paleolithic sites, such as Combe Capelle in France, roughly thirty-five thousand years ago, fragments of steppe bison (*Bison priscus*) skull bone with holes for fastening to the head have been found. Archaeologists speculate that these fragments served as war helmets, or perhaps as ceremonial headgear. The shield, too, was made of wood or hide; the oldest surviving shield dates to the Neolithic, roughly six thousand years ago, found in a marsh in Italy, but given indirect evidence, marks of club impact on the bones of the left forearm, showing that victims tried to deflect blows with the arm rather than with a wooden shield, which would leave no trace of itself, simple wooden shields were likely far older, at least twenty thousand years.

With the emergence of armor and the shield, an arms race in the true sense began. Stronger weapons, heavier, with sharper edges, were made to pierce armor. Thicker armor, more layers of hide, or the addition of bone, was made to withstand weapons. This cycle, offense against defense, has been the driving engine of innovation throughout history. In the Paleolithic, this competition was still in its earliest stages, but its seed had been planted. In later periods, the Bronze and Iron Ages, metal armor and weapons designed to penetrate it transformed the arms industry.

The mace and the club, owing to the high physical strength required for effective use, became the weapon of elites, in the military-social sense. Tribal leaders, hunting captains, and the bravest warriors typically carried a stone mace, and later a metal one. This weapon was a direct symbol of their physical power, and thus their leadership. In Paleolithic burials, such as the burials at Sungir in Russia, twenty-eight thousand years ago, young men, likely princes or distinguished warriors, were buried with decorated ceremonial maces, with handles of engraved ivory, while women, children, and ordinary men had no such weapon. This shows that the mace was a mark of mature manhood and high social standing, and was not permitted to women or ordinary individuals.

The Myth of the Mace in World Cultures

In the mythologies of the world, maces remained a symbol of raw power and the conquest of primal fears. In Greek myth, Heracles crushed monsters with his wooden club. In Norse myth, the god Thor destroyed giants with his hammer, Mjölnir. In Hindu myth, Vishnu, the preserver god, carries a mace named Kaumodaki, symbolizing power, admonition, and the restoration of cosmic order in battle against demons. In Chinese myth, the staff known as the Ruyi Jingu Bang, mentioned in the novel *Journey to the West*, is the weapon of the Monkey King, Sun Wukong; taken from an iron pillar of the dragon kings' palace, this staff can change size, weighs 13,500 pounds, more than six tons, and symbolizes the conquest of natural limits and the triumph of ingenuity over brute force.

In Persian culture and in Ferdowsi's national epic, the *Shahnameh*, the most important mythical mace is the ox-headed mace of Fereydun. Fereydun, a king of the Pishdadian dynasty, upon learning from his mother that Zahhak had killed

his father and usurped the throne, sets out, together with Kaveh the blacksmith, who raises the Kaviani banner, to do battle with Zahhak. Fereydun's principal weapon in this battle is a mace whose head is shaped like the head of an ox and which carries a magical power. According to the *Shahnameh*, Fereydun receives the ox-headed mace from the warden of Iran's border. The mace is so heavy and powerful that no one but Fereydun can lift it. When Fereydun reaches Zahhak's palace, he strikes Zahhak's head with the mace, but at the command of the angel Soroush he refrains from killing him, and instead orders him chained within a cave on Mount Damavand. A famous couplet of Ferdowsi's, rendered here in translation rather than the original, describes how Fereydun raised the ox-headed mace and struck, not to kill, but to bring his enemy down and take him captive. The ox-headed mace of Fereydun is not merely a physical instrument but a symbol of legitimate power, the divine farr, and the triumph of good over evil. The ox's head atop the mace is likewise rooted in ancient Iranian belief, which regarded the ox as a symbol of fertility, strength, and the god Bahram, deity of war and victory. In comparative mythology, Fereydun's ox-headed mace belongs to the same family as Thor's Mjölnir and Heracles' club, but unlike them, Fereydun's mace is not merely an instrument of crushing; it is also a sign of justice and divine farr, and its function is less about physical destruction than about restoring moral and cosmic order to the world. In Persian popular culture, the ox-headed mace continued to appear in heroic tales for years after the *Shahnameh*, passed down from Fereydun to later generations as a symbol of kingship and legitimate power.

The mace also functioned as a judicial weapon. In some tribal societies, a commander would strike the head of a condemned transgressor with his own mace. A blow from the mace to the head was a swift and merciless death sentence. In this way, the mace also became associated with punitive justice. Political and military power were, in that era, one and the same. Whoever held the mightiest mace could make the laws and punish their violation. This linkage continued throughout every civilization that followed.

Despite all their effectiveness, percussive weapons had serious limitations that later led to their displacement. They were effective only at very close range: to land a blow, one had to close to within a meter of the enemy, exposing oneself to a counter-blow; the chance of survival in hand-to-hand combat with a mace was low, unlike the bow, with which an attacker could fire from a distance and flee. They depended heavily on physical strength and stature: weaker individuals, women, children, the elderly, the sick, and even short-statured men, could not use these weapons effectively, since the weight of a mace, up to 1.5 kilograms, and the force needed to swing it exceeded their capacity. These weapons were unequal and elitist. A strong man with a mace could fell ten weak men. For collective defense, equalizers such as the bow and arrow were needed, so that the weak could kill the strong from a distance; the bow and arrow was a revolutionary development in this regard (Chapter Eight). They lacked precision: a mace blow is a sweeping, rotational motion. One cannot target a specific point on the enemy's body unless very close, less than fifty centimeters; at a distance of one meter, the chance of striking the head or shoulder depends heavily on luck. By comparison, a knife blade or spear has far greater precision. And they carried a high energy cost: swinging a heavy mace, one kilogram, repeatedly and quickly exhausts the muscles of the shoulder, arm, and back. After a few blows, five or six, accuracy and power drop sharply, and subsequent blows become weak and ineffective. In group battles that could last hours, holding and repeatedly swinging a mace was practically impossible. Lighter weapons, the blade, the spear, consume less energy and can be used for far longer without fatigue.

For these reasons, percussive tools, the mace and the club, gradually gave way on the main battlefield to cutting and penetrating weapons, the sword, the dagger, sharp-tipped spears, which offered greater precision, effective range (the spear), and physical efficiency (lightness). But they never fully vanished from the battlefield. Maces remained the primary weapon in certain cultures, such as the Inca and Aztec civilizations of the Americas. The club and the baton are still used by police forces today for crowd control, since a blow from a club is less dangerous than a gunshot and can incapacitate a person without killing them.

Several archaeological sites have yielded direct evidence of injuries from maces and clubs on the skeletons of early humans. At the Sidi site in Morocco, roughly fifteen thousand years ago, a human skull, female, roughly thirty-five years old, was found with a round, penetrating depression in the left parietal bone, near the crown. The cavity, roughly three centimeters in diameter and 1.5 centimeters deep, matches the tip of a hemispherical stone mace. The victim was likely standing, struck from behind and above, and died almost immediately, within seconds, from brain shock and internal bleeding. At Covan Cave in France, roughly twelve thousand years ago, three male skeletons in a mass burial, a shallow pit in the cave floor, all show multiple fractures in the bones of the hand and forearm (the ulna and radius) and skull (parietal and frontal). The forearm bones, especially the ulna, in two skeletons show linear and spiral fracture patterns clearly caused by a wooden club, not a stone mace. After the arms were broken, a final blow was delivered

to the skull with a stone mace. This site is one of the best examples of the stages of hand-to-hand combat in the Paleolithic. In the Orinoco valley in Venezuela, Stone Age, roughly five thousand years ago, though later than the Paleolithic period, a petroglyph on a rock face depicts two warriors holding maces and fighting. This carving shows that combat with the mace continued into the Neolithic in the Americas.

A notable point: at many sites, the skeletons showing such injuries are generally young and middle-aged men, twenty to forty years old. The pattern of injury, blows from the front (to the forehead and face) and from the side (to the hand and arm), indicates participation in hand-to-hand combat. Women, children, and older men generally show no such marks, mace-inflicted injury, meaning they likely did not take part in combat, or, if killed, were killed by other means, such as arrows, strangulation, or an axe blow. This gender difference in the pattern of violent death indicates that combat roles were assigned mainly to men in the Paleolithic.

Chapter Summary

Chapter Six has shown that percussive tools, the club and the mace, were humanity's first serious attempt to move beyond the limits of the body in the realm of violence. With these weapons, a person could strike with a force many times that of a bare fist, shatter bone, and bring down an animal, or a human. The logic of these weapons was physical power and the courage to close the distance. Unlike the spear, which created distance, the mace and club kept violence close and personal. But these same weapons carried major limitations: very short range, the need for high muscular strength, rapid energy depletion, low precision, and a high risk of mutual injury. These limitations pushed early humans to think about other weapon designs, weapons that would not require close contact, would target with greater precision, and would not depend on extraordinary physical strength. The answer was penetrating and cutting weapons, the dagger, the sharp-tipped spear, and later the sword, which we turn to in Chapter Seven.

Chapter 7

Penetrating Weapons and the Birth of the Logic of the Cut

From the Accumulation of Mass to the Concentration of Force

Percussive tools, the club and the mace, however effective, carried one fundamental flaw: to inflict serious injury, they necessarily had to drive a large volume of material, wood or stone, into the target's body at high speed. This process consumed a great deal of energy and made the outcome heavily dependent on the user's physical strength. But another category of weapon existed that operated on a different logic entirely: rather than accumulating mass and speed, it concentrated force on a single, very small point. These weapons are called piercing and slashing weapons. The physical principle at work here is simple: pressure equals force divided by the area of contact. If the area of contact is made extremely small, for instance, the tip of a blade only a few tenths of a millimeter thick and a few microns wide, even a small amount of force generates enormous pressure, many atmospheres, capable of piercing skin, flesh, and even bone. In this way, even a physically weaker person could, with a sharp blade and without expending great force, inflict a fatal wound on the strongest of enemies. This democratization of violence is one of the greatest transformations in the history of weapons, since it removed power from the exclusive domain of the physically massive and placed it in the hands of the agile, the skilled, and the precise.

In the Paleolithic, piercing and slashing weapons emerged in two principal forms: the dagger and the long blade, which later evolved into the sword. These weapons transformed not only the physics of violence but its psychology and sociology as well. With a dagger, a woman or a youth, with less physical strength, could bring down a burly warrior with a single precise strike to the neck, severing the carotid artery or windpipe, or to the groin, the femoral artery. This capacity upended the structure of power: power was no longer confined to the strongest muscles, but belonged to those who could strike more precisely and more calmly, and sometimes more cunningly. In Greek myth, Perseus kills Medusa with his dagger, avoiding her gaze and striking from the side. In Norse myth, Sigurd brings down the dragon with his sword by striking from behind, at its weak point. These archetypes show that precision and skill, and sometimes deception, have always triumphed over raw strength.

The Stone Dagger: The First Weapon Designed Exclusively to Kill Humans

The stone dagger was made by finely flaking a long, narrow blade of chert, obsidian, or flint stone. Its length was usually between ten and thirty centimeters, and its edge was sharpened on both sides, unlike a single-edged blade used for ordinary cutting tasks such as a hunting knife. The dagger can be considered the first weapon designed solely to kill humans, for several reasons: it was too short and brittle for butchering animals, skinning, portioning meat, a longer, sturdier blade such as a hand axe being better suited to that task; its point was so sharp and narrow, with a tip angle of less than thirty degrees, that it was optimized for penetrating human skin and soft tissue, rather than the thick hide and coarse fur of large animals such as bison and horses; and it could easily be concealed at the waist or beneath clothing, in a leather sheath, and was ideal for a surprise killing, an ambush, an assassination, a sudden altercation, while a spear or axe could not be so easily hidden.

The oldest stone daggers found belong to the Aurignacian culture in France, roughly thirty-five thousand years ago. In that era, modern humans, Cro-Magnons, used long, narrow blades, made with an advanced core-preparation flaking technique, to craft delicate daggers. Some of these daggers had handles of bone or antler, attached with sinew, sometimes engraved with animal figures, horse, bison, cave lion. These decorations show that the dagger was not merely a tool but also a status symbol and a work of art. In the Sungir burials in Russia, twenty-eight thousand years ago, a teenage boy, fourteen or fifteen years old, was buried with two decorated stone daggers, bone handles set with ivory beads, indicating he belonged to an elite class, perhaps the son of a tribal chief, and that the daggers were a mark of his status and skill, shown in rites of passage.

Technically, making a stone dagger was difficult and time-consuming, requiring the skill of a master flintknapper. The steps involved selecting a high-quality stone core, free of cracks and with a fine-grained crystalline structure; Levallois core preparation to produce a long, narrow blade, up to twenty centimeters, with a length-to-width ratio of at least three to one; sharpening the edges by pressure flaking, using a firm bone or wooden tool to detach tiny flakes from the edge; and, if the handle was made of bone, drilling it and attaching the blade with sinew and resin, tree gum.

Making a fine dagger could take a skilled craftsman several days, ten to twenty hours of continuous work. This enormous investment of time and skill in a single weapon shows that human groups placed great value on a weapon for killing humans and were willing to devote their resources to it. Unlike the hand axe, which anyone could make, the dagger was the product of a specialized craftsman and was likely traded.

The Logic of the Wound, the Bleeding, and the Gradual Death

Whereas the mace, with a single blow, high energy over a wide surface, shattered the skull and caused immediate death, within seconds, the dagger and the slashing blade created a deep wound, several centimeters, and heavy bleeding, which might not kill immediately, unless a major artery was struck, but would incapacitate the person within minutes to hours, depending on the location of the wound, and then kill through blood loss, hypovolemia, or infection, sepsis. This gradual death mattered for several reasons.

First, the victim had time to cry out for help or to flee, which could trigger a collective defense. For this reason, using a dagger in war, as opposed to an ambush, required complete surprise, likely while the victim slept or from behind, so the victim had no chance to cry out. Otherwise, the victim's cries could alert other group members and put the attacker at risk.

Second, the deep wound from a dagger, owing to the stone or bone surface being contaminated with soil bacteria and animal waste, often became infected. In an era before antibiotics, and even before the discovery of microbes, blood infection, sepsis, was nearly always fatal, within days to weeks, even if the initial wound was not especially severe and the victim managed to escape. Thus, even a superficial dagger wound to the muscle could bring an enemy down in the long run, death by fever and blood poisoning. This made the dagger a cheap weapon for wars of attrition.

Third, psychologically, for the attacker and onlookers alike, seeing the flow of blood, red and warm, and hearing the victim's cries of pain had a profound effect on morale. Cutting replaced the raw violence of the mace, crushing, the sound of shattering bone, with a theatrical violence, the bloody scene, the scream, the convulsive movement. In many cultures, dagger fighting, and swordsmanship more broadly, was revered as a martial art, such as Zen swordsmanship in Japan, kendo, or European fencing, scherma, while the mace and club always remained a crude, brutal, and low-class instrument.

Cutting also lowered the psychological threshold of violence. Unlike the mace, which delivered a terrible blow that the attacker directly felt as shattering bone, the dagger, with a soft, gentle motion, sliced through skin and sank in. This gentle motion was often interpreted by the attacker's mind as less horrifying than striking with a mace. This phenomenon is called increased psychological distance through mechanical efficiency. The more efficient, and lighter, a weapon is, the easier and less exhausting its use appears. Studies of present-day tribal societies show that the rate of violence in groups using sharp blades is higher than in groups using only clubs and maces, because psychological barriers, the ease of killing, are reduced.

The Dagger in Ritual and Burial

Archaeological evidence shows that daggers were often placed as valuable, symbolic objects in graves and ritual sites. In the Arechi cave in Italy, roughly thirty thousand years ago, a man, thirty-five to forty years old, was buried with two decorated stone daggers, bone handles engraved with fish and bird motifs. Beside him lay red ochre and a deer antler. This costly burial shows that the deceased was likely a distinguished warrior, skilled with the dagger, or a tribal leader, and that his community wished to preserve this identity even in death.

The dagger also played a role in boys' rites of passage. In some hunter-gatherer tribes, such as African tribes and Native American peoples, an adolescent boy had to kill a small game animal alone, with a stone dagger, or later a metal knife, and skin it, to be accepted as a man, a warrior. This rite symbolized the ability to cut and to separate, life from death, friend from enemy, a skill essential to both hunting and war, cutting the enemy's throat. In this way, the dagger also became a tool for defining gender identity, manhood.

From Dagger to Sword: Length, Reach, and the Martial Art

The next innovation, which occurred mainly in the age of metals, bronze, but was rooted in the stone dagger, was the gradual lengthening of the blade. A dagger thirty centimeters long is suited to close, personal blows, at a distance of less than fifty centimeters. But if the blade is extended to sixty centimeters or more, the result is a weapon called the sword. The sword first appeared in the Bronze Age, roughly thirty-five hundred years ago, in Mesopotamia and Anatolia, but its conceptual roots, the long, double-edged blade, trace back to the stone daggers of the Paleolithic. The sword offered three important advantages over the dagger. Greater reach: with a long sword, seventy to ninety centimeters, one could strike an enemy from a greater distance, nearly a meter, without being exposed to his knife, sword combat took place at a distance of one to 1.5 meters, while dagger combat occurred at less than half a meter. This increased distance improved the attacker's safety. Swinging and arcing strikes: a sword can be used for both a slashing blow, with the edge, and a piercing blow, with the point. Curved swords, such as Asian and European curved blades, are ideal for slashing, cutting soft tissue and striking the neck and hands, while straight, double-edged swords are better suited to piercing, driving into gaps in armor. The dagger is primarily a piercing weapon. And a systematized martial art: with a sword, one can parry a blow with the flat or edge of the blade while simultaneously counterattacking. The dagger is too short to parry an enemy's blow. Swordsmanship became a complex system of movement requiring years of practice and the mastery of balance, speed, and technique. Dagger fighting is far simpler and more instinctive.

In ancient civilizations, the sword became a symbol of chivalry and nobility, while the dagger was always associated with treacherous, nocturnal, backstabbing murder. The dagger was the weapon of the professional assassin, the sword the weapon of the honored warrior. This duality persists to this day. Even so, from an archaeological and technological-evolutionary standpoint, both share a single root concept: the concentration of force on a small point to penetrate the enemy's body and create a deep wound.

The Myth of the Sword in World Cultures

In various cultures, legendary swords became symbols of sanctity, absolute power, and, at times, a curse.

Zulfiqar (Islam and Iran): the sword of the Commander of the Faithful, Ali ibn Abi Talib. According to historical and hadith sources, Zulfiqar was a two-pronged, or double-edged, sword that came to the Prophet as war spoils at the Battle of Badr, or Uhud, and was given by him to Ali. Its name means splitter of the spine, or possessor of ridges, referring to the notches along the back of the blade. At the Battle of the Trench, Ali is said to have used this sword to strike down and cleave Amr ibn Abd Wudd, a renowned champion of the Quraysh. Afterward, a call was said to have rung out declaring that there was no youth like Ali and no sword like Zulfiqar. In Persian-Islamic culture, Zulfiqar stands as a symbol of justice, divine courage, and spiritual power.

Excalibur and the Sword in the Stone (Britain and the Celtic tradition): in Celtic mythology and the legends of King Arthur, Excalibur symbolizes the divine right to rule and the unity of kingship. According to legend, Merlin, the court magician, set an enchanted sword into a stone and anvil, decreeing that only the true king of Britain could draw it out. Arthur, raised as an ordinary youth rather than an heir to the throne, drew the sword from the stone and proved himself the rightful king. Excalibur's power lay not only in its sharpness but in its scabbard, which rendered its bearer immune to any wound.

Gram, or Balmung (Scandinavian and Germanic tradition): in Norse mythology and the German epic the *Nibelungenlied*, the sword Gram was the only blade capable of piercing the hide of the dragon Fafnir and slaying him. The hero of the tale, Siegfried, or Sigurd, after reforging and resharpening the broken blade, brings down the dragon. Gram symbolizes a weapon that can destroy a monster while also bringing ruin upon its own bearer through Fafnir's curse.

Kusanagi-no-Tsurugi (Japan): one of the three Imperial Regalia of Japan, symbolizing courage and virtue and affirming the emperor's legitimacy as a descendant of the sun goddess Amaterasu. According to Shinto mythology, this sword was drawn by the storm god Susanoo from the tail of the eight-headed serpent Yamata no Orochi. Kusanagi means grass-cutter. Unlike Western legendary swords, Kusanagi was never used on an actual battlefield and was used mainly in coronation rites.

The Khopesh (Egypt): a sickle-shaped sword introduced from Syria during Egypt's Middle Kingdom, which became a symbol of pharaonic power. With its curved outer edge, the khopesh was designed both to cut and to hook an enemy's shield. In Egyptian myth, the sun god Ra defeats the serpent of chaos, Apep, in the underworld with a curved sword.

Nandaka (India): the sword of Vishnu, the preserver god. Nandaka, meaning source of joy, symbolizes divine knowledge and the cutting away of ignorance and darkness. In the epic Ramayana, Rama, an avatar of Vishnu, uses this sword in battle against Ravana, the demon king. Unlike Western swords, which symbolize military power, Nandaka symbolizes spiritual enlightenment.

The swords Ganjiang and Moye (China): two legendary swords forged by a husband-and-wife blacksmith pair of the same names. After three years of labor, they produced two blades, a male sword and a female sword. Because the king was a tyrant, Ganjiang gave the king only the female sword and entrusted the male sword to his wife. Years later, their son avenges his father with the male sword. This legend symbolizes sacrifice, loyalty, and the curse of mastery.

Archaeological Evidence of Injuries from Cutting Weapons

Several sites have yielded skeletal injuries specifically attributable to a dagger, rather than a spear or club. At the Vasilou cemetery in Greece, roughly twelve thousand years ago, a middle-aged man, forty-five to fifty years old, shows a deep cut in the lower fourth rib on the left side, four centimeters long and one centimeter deep. The direction of the cut, top to bottom, at a thirty-degree angle, indicates the blow was struck with a dagger from behind while the victim was seated or bent over. The victim died within minutes from internal bleeding. At Costa Cave in Italy, roughly ten thousand years ago, the skeleton of a young woman, twenty to twenty-five years old, was found with two parallel cuts, 1.5 centimeters apart, on the left and right collarbones. The location of the cuts, near the major arteries of the neck, was lethal. This site shows that slashing violence was not confined to men. In the Loire valley in France, roughly eight thousand years ago, several skeletons, five men, two women, one child, were found with multiple cuts, four to seven, to the face (nose, jaw), neck (vertebrae), and hands (fingers). Remarkably, these skeletons received ceremonial burial, with personal belongings. In some of these skeletons, the forearm bones show a defensive parry fracture, meaning the victims deflected blows with their forearms. This shows that hand-to-hand combat with the dagger was common in that era.

The Transition from Stone to Metal and the Persistence of the Logic of the Cut

With the emergence of metallurgy, first copper, then bronze, then iron, stone blades gave way to metal ones. The logic of cutting and piercing was not only preserved but strengthened. Metal held three great advantages over stone: durability and resistance to fracture, a stone blade could shatter on impact with bone, whereas a metal blade faced no such problem; the ability to be resharpened, a stone blade, once dulled, was essentially beyond repair, whereas a metal blade could be sharpened again and again; and the ability to be cast into complex shapes, through casting and forging. In the Bronze Age, the first weapon-manufacturing workshops were established in Mesopotamia and Egypt, producing thousands of swords and daggers in short order. Even so, the founding principles, concentrating force on a small point, creating a deep wound, were inherited from the Paleolithic. The Hittite bronze sword, the Roman iron dagger, and the Damascus steel blade are all descendants of the same Paleolithic stone dagger.

In the medieval period, longswords roughly 120 centimeters in length and weighing 1.5 kilograms were made. Swordsmanship became one of the seven chivalric arts, and fencing schools were established across Europe.

Chapter Summary

Chapter Seven has shown that penetrating and slashing weapons brought about a fundamental transformation in the logic of violence. They shifted power from the accumulation of mass to the concentration of force on a single small point. With the dagger, weaker individuals could bring down the strongest of enemies with a single precise strike. This democratization of violence changed the structure of power forever. At the same time, the dagger, as a weapon designed specifically to kill humans, took on symbolic and ritual functions as well. With the transition to the age of metals, the logic of cutting persisted in the form of bronze, iron, and steel swords. This chapter has also shown that cutting, beyond its physical advantages, carried deep psychological effects: gradual death, bleeding, and, most importantly, a lowered psychological threshold for the use of violence. The more efficient and sharper a weapon becomes, the easier killing with it becomes. This principle would later reach its peak in firearms and drones. By the end of this chapter, we can say that the logic of the cut and the logic of the throw have been the two central pillars of human violence over the past ten thousand years.

Chapter 8

Projectiles and the Revolution of Distance in Violence

Separating the Messenger of Death from the Killer's Body

All the weapons examined up to this chapter, the club, the mace, the dagger, the blade, required one essential condition: direct contact between attacker and target. Even the spear, which had the longest reach, still kept the attacker's hand upon it at the moment of the strike, so that he could feel the spear's shudder and the warmth of the blood. But projectiles abolished this condition forever. With a projectile, a person could enact violence from a distance, without knowing exactly where the blow landed, without seeing the color of the blood, and without hearing the victim's cry. The projectile made possible the separation of death from the body. This separation may be the single most important psychological and moral transformation in the history of weapons.

Here, a projectile means any object released toward a target using force stored in a tool. The oldest projectile was simply the stone that early humans threw to drive a predator away from a carcass. But these early projectiles were highly inaccurate, short-ranged, and carried negligible energy. Later inventions, the bow and arrow, the spear-thrower, the sling, addressed these limitations one by one and turned the projectile into a serious weapon of war. The projectile revolution brought three fundamental changes: first, it made safe distance a strategic principle; second, it replaced muscular strength with accuracy and skill; and third, it lowered the psychological threshold of killing to a considerable degree.

The Thrown Stone and the Sling: Cheap, Democratized Violence

The simplest projectile was a stone gripped in the fist and thrown at a target with the force of the arm. This method required no tool at all, and anyone, at any age or strength, could use it. At many Paleolithic sites, caches of round, smooth stones, about the size of a tennis ball, have been found, likely used as hand-thrown projectiles.

But the next innovation was the sling: a leather cord or strap with a pouch fashioned into its middle to hold a stone. The slinger swung the cord above his head and then released one end. The stone left the pouch at very high speed, up to 100 kilometers per hour. The sling's effective range reached one hundred meters, with a maximum range of up to two hundred meters, and its impact force was enough to break bone and even dent metal armor. The sling appears in numerous historical sources. In the Bible, the young David brings down Goliath, the Philistine giant, with his sling, striking him in the forehead with a stone. In the army of ancient Rome, slinger units were recruited from the Balearic Islands, trained with this weapon from childhood. The oldest surviving slings date to the Neolithic, roughly eight thousand years ago, but given how quickly leather decays, far older examples likely existed.

The sling was the weapon of the ordinary person. It was simple to make, just a leather strap, and its ammunition, river stones, was available everywhere. In wartime, women and children could hurl stones at attackers from behind walls with a sling. For this reason, the sling served in many ancient civilizations, Egypt, Greece, Rome, Peru, as the weapon of auxiliary and militia forces. The sling was, in effect, the first economically efficient weapon of mass casualty, since it inflicted the greatest damage at the lowest cost.

The Spear-Thrower: Increasing Range and Penetration

The spear-thrower, briefly introduced in Chapter Four, is a tool thirty to seventy centimeters long that functions as an extension of the human arm. At its end is a projection that fits into a socket at the base of the spear. The thrower holds the spear-thrower, sets the spear into the hook, draws the arm back, and then, with a whip-like motion, brings the spear-thrower forward. The spear detaches from the hook and moves forward at roughly two to three times the speed of a hand throw.

Based on practical experiments, the spear-thrower can increase effective range from thirty meters to eighty meters, and maximum range up to 150 meters, while also increasing impact force by up to fifty percent. This increase in range and power allowed hunters to target large animals, such as mammoths, from a relatively safe distance. In war, the spear-thrower allowed infantry to launch several volleys of spears before the enemy could close the distance. Even

so, the spear-thrower demanded considerable skill. The oldest spear-throwers found belong to the Magdalenian culture of France, roughly eighteen thousand years ago. The rapid spread of the spear-thrower across Europe and Asia shows that this invention was welcomed by every human group. The spear-thrower remained the primary weapon until roughly two thousand years ago in certain regions, such as Australia and the Arctic, where the bow had not yet been introduced.

The Bow and Arrow: The Peak of the Distance Revolution

The bow was the greatest leap in projectile weaponry. Its principle is simple: bending a flexible piece of wood and suddenly releasing it to launch an arrow at high speed. But implementing this principle required a deep understanding of the properties of wood, animal sinew, and rudimentary aerodynamics. Making a good bow required days of work from a skilled craftsman, and raw materials often had to be sourced from particular regions.

The oldest surviving bows belong to the Holmegaard site in Denmark, roughly ten thousand years ago. But indirect evidence, small stone arrowheads found in layers dating to twenty or thirty thousand years ago in Africa, suggests the bow was invented at least thirty thousand years ago. The bow gradually replaced the spear-thrower across much of the world, since it offered greater effective range, up to 120 meters, higher accuracy at medium ranges, and a far faster rate of fire. The bow and arrow pushed distance to the maximum possible for a hand-operated mechanical weapon. An archer could loose his arrow from a distance beyond which the twang of the bowstring could not reach the enemy's ears. Before the target even realized what was happening, the arrow had already sunk into his body. This invisible killer played a critical role in ambushes, sieges, and the defense of fortifications.

Throughout history, different cultures developed specialized bows. The English longbow, famous from the Hundred Years' War, was made of yew wood and reached 1.8 to 2 meters in length. Its draw weight was between seventy and eighty kilograms, and it launched an arrow at sixty meters per second. Asian composite bows were made of wood, horn, and sinew, and performed better in arid climates. The Japanese bow, the yumi, asymmetrically designed, was optimized for use by mounted samurai.

How Projectiles Changed the Tactics of War

The advent of projectiles transformed military tactics at three levels. The first level: linear formation and mass fire. Archers formed ranks behind wooden shields or stone walls and, on the commander's order, loosed dozens of arrows at once toward the enemy's ranks. Mass fire inflicted heavy casualties and undermined enemy morale. The second level: asymmetric warfare. A group of mounted archers could strike the enemy from a distance without engaging directly. The steppe nomads, the Scythians, the Huns, the Mongols, used precisely this tactic, known as the Parthian shot, to crush great armies. The principle was simple: do not close the distance, shoot from afar, retreat, attack again. The third level: layered defense. Archers positioned behind a fortress wall could target attackers without being exposed to danger. To counter this, attackers were forced to build large shields or use their own skilled marksmen to neutralize the defenders.

The Psychological and Social Impact of the Bow and Arrow

Beyond tactics, the bow and arrow sharply lowered the psychological threshold of killing. A person who fires an arrow at an enemy from fifty meters away does not see the victim's face, does not hear the sound of breaking bone, and does not see the blood. This ignorance produced by distance made it easier for the archer to loose the string. Anthropological research shows that the rate of violence in groups possessing the bow is higher than in groups armed only with the spear and club. Socially, the bow and arrow placed power in the hands of the skilled, not necessarily the strong. A slender man with great skill in archery could be worth more on the battlefield than a burly champion. The world's first professional armies, such as the armies of Assyria and Achaemenid Iran, possessed dedicated archer units. The bow and arrow also made combat more anonymous. An enemy soldier was no longer so-and-so, son of such-and-such tribe, but a target in the second rank. This anonymization reduces empathy and facilitates killing.

Myths of the Bow and Arrow in World History

Arash the Archer (Iranian myth): the greatest and most sacred archer in Iranian history. After years of war between Iran and Turan, it was agreed that an arrow would be shot from Mount Damavand, and wherever it landed would mark the border between Iran and Turan. Arash draws his bow to its fullest and pours his entire being into the arrow. The arrow passes over the rooftops of cities and over mountains, and finally, after a long flight, lands beside the Jeyhun river, marking the eternal border of Iran and Turan. Arash gives his life in the act of loosing the arrow. Arash symbolizes sacrifice, patriotism, and the determination of territorial identity.

The bows of Apollo and Eros (Greece): in Greek myth, Apollo, god of music and poetry, is counted among the greatest archers. Apollo's arrows brought plague, sudden death, and calamity. Eros, or Cupid, by contrast, stirred love and desire in the hearts of gods and humans with his golden bow and arrows. This contrast, the arrow of death and the arrow of love, shows that distance appears in myth too as a decisive factor.

The bow Sharanga and the bow of Rama (India): in Hindu myth, the bow Sharanga is the celestial bow of Vishnu, the preserver god. Built by the architect of the cosmos, its essence is knowledge and wisdom. In the hands of Rama, an avatar of Vishnu, in the epic Ramayana, Sharanga becomes a symbol of justice and victory over evil.

The bow of Ra (Egypt): in ancient Egyptian myth, the sun god Ra travels each night by solar barge into the underworld to do battle with the great serpent of chaos, Apep. In this battle, Ra uses a bow, and with each sunrise he triumphs over Apep, order prevailing over chaos. Ra's bow symbolizes victory over darkness and the preservation of cosmic order.

Archaeological Evidence of Long-Range Combat

Several notable sites bear on this question. At the Jebel Sahaba site in Sudan, fourteen thousand years ago, of fifty-nine skeletons, twenty-one bear stone arrowheads embedded in their bones. The sex of the victims, twenty-two women, thirty-seven men, shows that women too were targets of long-range attacks. This site is among the oldest evidence of organized warfare in history. In the Rhine valley, Germany, seven thousand years ago, the skeleton of a middle-aged man was found with a stone arrowhead in a cervical vertebra. The angle of the arrow shows it was fired from a distance of roughly thirty to forty meters. The victim was caught by surprise, neither fleeing nor defending himself. At Lazo Cave in France, nine thousand years ago, several human skeletons were found with multiple arrow marks in the back and thigh. Archaeologists concluded that these individuals were shot from behind while fleeing a stronghold.

Limitations and the Transition to Larger Mechanical Weapons

Despite all their advantages, the bow and arrow had limitations. Their effective range was at most 120 meters, beyond which the arrow lost speed and drifted off course. Arrow penetration against the metal armor that became common in the Bronze and Iron Ages was insufficient; an archer had to aim for unarmored points. The rate of fire was also limited, and archers were vulnerable to cavalry charges. The bow lost effectiveness in rain, which loosened the wood, and in severe cold, which made it brittle. These limitations pushed humans to think about larger mechanical projectile weapons, such as the catapult, the war elephant, and later gunpowder cannon.

Chapter Summary

Chapter Eight has shown that projectiles transformed the concept of distance from a physical dimension into a strategic and psychological principle. With the projectile, a person could destroy an enemy from afar, without direct danger, and with a lower psychological threshold. This capacity reduced killing from a personal, heroic act to a technical skill. Projectiles transformed the order of the battlefield. Linear formations, mass fire, guerrilla warfare, and layered defense are all children of the projectile. Societies with superior projectile skill triumphed over societies that relied on the spear and sword. But this superiority was never absolute, since good armor and stone fortifications could neutralize the projectile's effect. This same competition, projectile against armor and fortification, has been the driving engine of innovation in every century since. By the end of this chapter, early humans possessed tools with which they could strike an enemy from a safe distance. This distance revolution gradually led to the concentration of power in the hands of states and professional armies. Even so, the bow ultimately proved no match for the iron armor and stone walls of

the Iron Age. The final answer to this limitation was gunpowder. With Chapter Eight, Part One, from Hunted Human to Nature's Hunter, comes to its close.

PART TWO

The Age of Metals, Fortifications, and Empires

Chapter 9

The Discovery of Metals and the Metallurgical Revolution: From Copper to Iron

The Decisive Moment: Roughly 3300 BCE, the Indus Valley, Southeastern Iranshahr (present-day Sistan)

It was dawn. Atarpat, a village metalworker, lit his clay furnace for the hundredth time. This time, he placed a green-colored stone brought down from the mountains into a heat-resistant clay vessel and covered it with charcoal. He raised the furnace's temperature by blowing through a clay pipe. Hours passed. At the point of frustration and despair, a spark suddenly flared, and out of the ashes appeared something bright and reddish. Atarpat drew it from the furnace with two wooden sticks. A drop of molten metal dripped to the ground and hardened. Pure copper, with a shine he had never seen in stone. Not only Atarpat, but the whole village gathered around. The tribal elder, touching the copper blade that Atarpat had hammered from that small ingot, said that this stone had a spirit, that it could die and be born again. From that day, the Stone Age ended and the Age of Metals began. Humanity had taken its first step toward the power to soften matter.

Eyewitness testimony, a mythic account from Ferdowsi's *Shahnameh* describing the first ironworking, rendered here in translation rather than reproducing the original verse, tells of Hushang, a king of the Pishdadian dynasty, who is said to have been the first to forge iron and sharpen a blade from it, an act that brought a new craft into the world and led people to bind armor upon their bodies.

From Stone to Copper: The First Step in Smelting

In the Neolithic, roughly ten thousand to four thousand BCE, humans were already familiar with native, naturally occurring copper. Pure copper fragments, found as sheets in riverbeds, were cold-hammered into blades, needles, and ornaments. But these fragments were soft, rare, and small. The transformation came when humans learned how to heat stones containing copper oxide, such as green malachite and blue azurite, in clay furnaces at roughly 1000 degrees Celsius. At this temperature, oxygen separates from the stone, and molten copper, melting point 1085 degrees, flows from the base of the furnace. This process, smelting, was revolutionary: for the first time, humans drew a substance out of the heart of stone and shaped it as they wished. The first smelted copper objects in West Asia and the Iranian plateau date to roughly 5000 to 4000 BCE. Tepe Sialk near Kashan and Tepe Hissar near Damghan hold evidence of some of the oldest copper smelting in the world. But pure copper was not especially well suited to weapons of war: it was too soft, dulled quickly, and bent on impact.

The Bronze Revolution (3300 to 1200 BCE)

The next great innovation was adding a small amount of tin, roughly five to fifteen percent, to molten copper. The new product, bronze, had far greater strength, its hardness two to three times that of pure copper, a lower melting point, roughly 950 degrees, and could be cast in stone molds. Bronze swords could hold an edge sharper and more durable than copper. Bronze helmets and armor protected soldiers against mace blows and stone arrows. Bronze production required extensive trade: copper was found in Cyprus, from which its name derives, and tin in Afghanistan, Bohemia, and Cornwall. In this way, the first international trade networks took shape to supply the raw materials of weaponry.

In this age, great civilizations rose to power on the strength of bronze weapons. In Mesopotamia, war chariots armed with bronze spears turned Assyrian infantry into the engine of several empires. In Egypt, the pharaohs of the Eighteenth Dynasty conquered Syria and Nubia with bronze, sickle-shaped khopesh swords. In Iran, the civilization of Elam, and later the Medes, relied on bronze weapons. In Europe, Mycenaean culture, which recounts the epic of Troy, produced the bronze Dendra armor. Bronze's weakness was the scarcity of tin. An empire that lost access to tin was disarmed. This vulnerability laid the groundwork for the Bronze Age collapse around 1200 BCE.

The Iron Age: The Democratization of Weapons and the Birth of Popular Empires (from 1200 BCE onward)

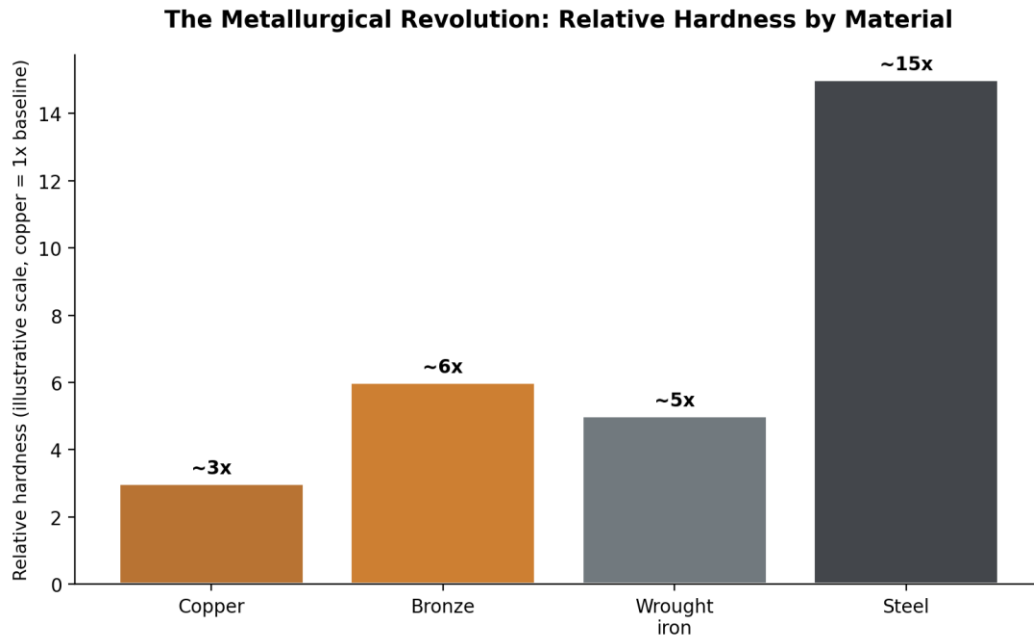


Chart: Relative hardness of copper, bronze, wrought iron, and steel (author's diagram, illustrative, not laboratory-calibrated values).

Roughly 1500 BCE, in Anatolia, present-day Turkey, and the Caucasus, humans learned how to smelt iron ore in tall furnaces at 1200 degrees to obtain a spongy bloom of iron. Then, through repeated heating and hammering, they introduced carbon into the iron to produce low-carbon steel. Unlike bronze, iron was found in local deposits almost everywhere in the world. Its extraction and production were cheap, and iron weapons were no longer the exclusive privilege of elites. Ordinary infantry too could possess an iron sword.

The first people to make extensive use of iron weapons were the Hittites of Anatolia, roughly 1300 BCE. But after the collapse of the Hittite empire, ironworking knowledge spread rapidly across the Middle East and Europe. The Philistines, the Assyrians, and later the Greeks and the Romans equipped their armies with iron swords, spears, and armor. The Roman legionary, with his gladius, a short iron sword, and lorica segmentata, banded steel armor, was the very symbol of this age. Iron democratized war. A peasant revolt armed with iron sickles and homemade swords could challenge the armies of bronze-armed kings.

Eyewitness testimony, Pliny, the Roman historian of the first century CE, wrote in his Natural History, rendered here in translation, that iron is at once the best and the worst instrument of life, since with it we plow the earth and build our homes, and with it we wage war and bring death; iron moves borders and creates empires.

The Consequences of Metallurgy for Weapons

Copper: highly malleable and lustrous, but soft and quick to dull. Its signature weapons were the dagger, the spear point, and ornaments. Bronze: high hardness, two to three times that of copper, easy to cast, but dependent on tin and relatively brittle. Its signature weapons were the sword, such as the khopesh, scale armor, and the helmet. Iron: abundant, cheap, capable of mass production, but requiring higher temperatures and prone to rust. Its signature weapons were the long sword, the spear, and chainmail armor.

With mastery over iron, humanity never returned to the Stone Age. Even today, the main structure of tanks, cannons, and ships is built from steel, an alloy of iron. Metallurgy taught humans to change the hidden properties of materials. This knowledge later led to the making of phosphor bronze, Damascus steel, and eventually stainless steel and titanium alloys. The transition from stone to metal was thus not merely a technological transformation, but the birth of materials engineering as the backbone of human weaponry.

Chapter 10

Achaemenid Chariots, Parthian Cataphracts, and the Immortals

I. The Achaemenid Empire: From Persia to the World

In the middle of the sixth century BCE, Cyrus the Great, of the Achaemenid house, rose up in Persia, in the southwest of present-day Iran, and in less than twenty years crushed the empires of Media, Lydia in Anatolia, and Babylon in Mesopotamia, founding the largest empire the world had yet seen. At its height, under Darius the Great, 522 to 486 BCE, the Achaemenid Empire stretched from the Indus, present-day Pakistan, in the east to Thrace in the Balkans and Libya in the west, and held a population of more than fifty million, roughly forty-four percent of the world's population at the time. Sustaining so vast an empire required an army that was powerful, well organized, and equipped with the most advanced weapons of the age. The Achaemenid army held the empire's borders for two hundred years not through sheer numbers, which sometimes reached three hundred thousand, but through organization, ethnic diversity, drawing on the martial skills of many peoples, and tactical innovation, combining infantry, cavalry, chariots, and archers.

Contrary to the common image found in Greek sources, which portray the Achaemenid army as an undisciplined mass of slaves, archaeological evidence, including the inscriptions of Persepolis, Susa, and Bisotun, together with the account of Xenophon in the *Cyropaedia*, describes a hierarchical, orderly structure in which units were organized on a decimal system. Every ten soldiers had a *dahbad*, a squad leader; every hundred soldiers a *sadbad*, a company commander; every thousand soldiers a *hazarabad*, a chiliarch; and every ten thousand soldiers a *baiwarabad*, a division commander. This decimal system, later adopted by the Roman army in its division into centuries of a hundred men, allowed for the rapid transmission of orders on the battlefield, using trumpets, horns, and colored banners, and preserved the cohesion of units amid the chaos of war. Each soldier had a defined duty and was not to move from his position without command. This discipline, rooted among the Persians and Medes in military training that began in childhood, from the age of five, distinguished the Achaemenid army from an undisciplined mass of rebels and mercenaries.

The core of the army was formed by the Iranians, the Persians and Medes, who were its most trained and loyal troops and took part in every campaign. Alongside them, allied and subject forces from across the empire, Egyptians, Babylonians, Phoenicians, the Greeks of Asia Minor, Indians, Scythians, and others, served in the imperial host with their own native weapons and tactics. This diversity, contrary to what certain one-sided Greek accounts imply, such as Herodotus, who mockingly describes the composition of Xerxes's army, was not a weakness but a strength of the Achaemenid army, since each people brought its own specialized weapons to the field: skilled Median archers with composite bows, Persian marksmen with bow and scale armor, heavily armed Bactrian spearmen with long spears, and the scythed chariots of India and Scythia, which spread terror across the open plains, all combining into a single army that the Greeks recalled with astonishment, and fear. Even so, the central role in this composite army belonged to the Persian and Median warriors, who, with weapons such as the short sword, the *akinakes*, the long spear, the composite bow, and scale armor of metal and leather, formed the most elite infantry and cavalry force. Darius the Great boasts in the inscription at Naqsh-e Rostam that these are the countries over which he, King Darius, rules, Persia, Media, Elam, and so on, emphasizing that his army was a reflection of unity within diversity.

II. Achaemenid Weapons and Equipment: The Akinakes, the Composite Bow, and Scale Armor

Persian and Median warriors were equipped with a variety of weapons for combat at different ranges, from long-range archery to hand-to-hand fighting. Their standard sword was called the *akinakes*. This short sword, forty to fifty centimeters, with a double-edged, curved blade, shaped like an iris petal or a bean, was designed for slashing and piercing wounds in close combat. Both cavalry and infantry could easily draw the *akinakes* from its leather sheath, worn at the waist. This curved sword, later seen also among the Scythians and Parthians, was optimized for cutting rather than thrusting. The *akinakes* is clearly visible in the relief carvings of Persepolis, in the hands of courtiers and soldiers, and in the Oxus Treasure, a collection of Achaemenid gold. The long spear, two to 2.5 meters, with a bronze or iron point and a wooden shaft of ash, was the primary weapon of the heavy spearmen who stood in the front ranks, used against cavalry charges, such as the Scythians, and against Greek hoplite spearmen.

Even so, the Achaemenid army was known above all for its skilled archers, Persian, Median, and Scythian. The composite bow, made of wood, maple or ash, animal sinew, deer or cattle, and horn, mountain goat, held two decisive advantages over the simple wooden bows of the Greeks, which were made from a single piece of wood: far greater draw weight, up to seventy or eighty kilograms, against thirty to forty kilograms for a simple wooden bow, which launched the arrow with more energy, up to sixty meters per second, increasing its penetration against an enemy's leather or bronze armor; and smaller size, one to 1.2 meters, against 1.5 to two meters for the long Greek bow, which made it easier to use on horseback and in tight spaces between ranks of spearmen. Persian archers generally did not wear heavy armor, only a leather helmet and a short tunic, since their position in battle was behind their own spearmen, and in the event the front lines broke, they could retreat quickly on horseback. This was not a sign of weakness, but an awareness of their tactical role in the fight. Each archer carried a quiver called a gorytos at his waist, which held both arrows and the bow itself, in its unstrung, curved state, protecting it from rain and moisture. In battles between Persia and the Scythians, and Persia and the Greeks, Achaemenid archers usually emerged victorious.

III. Scale Armor and Defensive Equipment

Persian and Median soldiers, especially the elite, used scale armor, made of small metal rings or plates, bronze or iron, sewn onto a leather or linen backing. This armor, up to ten kilograms, was light compared to a solid bronze cuirass and offered good resistance against spear and arrow strikes, which were often fired from a distance. Scale armor was flexible and did not restrict movement. Oval or rectangular wicker shields, called *spara*, wood covered in leather and sometimes a layer of bronze, were also used for protection against enemy fire, especially Greek archers. Soldiers' heads were protected by metal helmets, bronze or iron, with hanging cheek guards that shielded the face from cuts. The Persian helmet, examples of which have been found at Persepolis and Susa, was generally hemispherical, similar to the Greek helmet, with a ridge to deflect axe or sword blows. Light infantry, such as Scythian archers and Greek mercenaries who served as hoplites in the Achaemenid army, had no such armor and carried only light leather shields, *peltas*. Archers, too, forwent heavy armor to preserve their agility, for running and repositioning, and relied only on the bow, the quiver, and a dagger. Each archer carried up to thirty arrows into battle, and behind them, supply gatherers with donkeys and camels carried reserve arrows.

IV. The Scythed Chariot: The Most Terrifying Achaemenid Weapon

One of the greatest military innovations of the Achaemenids, borrowed from the Scythians and the Indians, was the scythed chariot, brought into use in the first half of the fifth century BCE, in the era of Darius the Great and Xerxes. These chariots, always described in Greek sources, including Xenophon and Arrian, as shattering and terrifying to enemy ranks, carried scythe-like blades of iron or bronze mounted on the axles of their wheels: two blades pointing downward, at the end of the wheel axle, to cut the legs of enemy soldiers, and two blades pointing upward, just above them, to cut the bellies of horses and the shafts of enemy spears. As the chariot charged through enemy ranks, these blades cut through enemy infantry, cavalry, and horses like a scythe through a wheat field. The scythed chariot typically had four horses, sometimes two, and carried three men: a driver, in heavy armor, an archer, to fire from a distance, and a spearman, for close combat once the enemy ranks had broken.

According to historical sources, Cyrus the Great, in his wars against Lydia and the Scythians, and Darius the Great, in his campaigns into Scythia, 513 BCE, and Greece, the battles of Marathon, 490 BCE, and Salamis, 480 BCE, made use of the scythed chariot. But its effect against the Greeks was limited, since the Greeks found ways to counter its terror through uneven terrain, as at Marathon, narrow passes, as at Salamis, and by breaking their own ranks into a disciplined phalanx. At the Battle of Gaugamela, 331 BCE, between Darius III and Alexander of Macedon, the Achaemenid scythed chariots were halted by a hail of arrows and the long Macedonian spears, six meters in length, and the wounded horses turned back into their own ranks, causing chaos. Even so, the scythed chariot was highly effective on open plains, in Mesopotamia, Anatolia, and India, against light infantry and unarmored cavalry. Its main use was to break the order of the enemy's formation, opening a path for the cavalry, rather than direct slaughter. The scythed chariot was a symbol of imperial power and wealth, and was also used in ceremonial processions.

V. The Immortals: The Legendary Force of Ten Thousand

Without doubt, the most famous unit of the Achaemenid army was the Immortals, known in Old Persian as the Anusiya. Herodotus, the father of history, called this force the Athanatoi, the Immortals, and gave two reasons for the

name. First, its number always held steady at the astonishing figure of ten thousand men, since in battle, a wounded or fallen soldier was instantly replaced by another from a reserve pool, so that whether at the beginning or the end of a battle, their number was always ten thousand. Second, the Immortals were, in the truest sense, a standing and permanent force of the Achaemenids, at a time when Greece and other civilizations had not yet developed standing professional armies. From the time of Darius the Great, or perhaps Cyrus, the Achaemenids maintained this fixed unit of ten thousand men, who served not only as guards of the king and the royal family, but as an effective vanguard force, the core of the army, in every war. A regiment of a thousand men from this force, who carried golden spears, or spears with golden counterweights shaped like apples, was called the Apple Bearers, and stood directly in front of and beside the king on the battlefield. They were the king's immediate guard, and at royal banquets they stood closer to the king than other soldiers. Only this golden-speared regiment carried a shield and full armor; the other thousand-strong units of the Immortals used their silver spears alongside a bow and dagger. A fully equipped Immortal soldier carried an *akinakes* at his waist, a small axe for close combat, a spear two meters long, and composite bows, two primary bows and a spare bow in the quiver, along with a quiver full of arrows, up to thirty, and a sling with throwing stones. Their bow was a long, special bow, similar to the Median bow, more powerful than the ordinary infantry bow. Their clothing and armor, golden or silver scale armor, also set them apart from other soldiers, and the terror felt by Greek warriors, who encountered the Immortals in the Greco-Persian wars, at the sight of their gleaming bodies on the battlefield is well reflected in the writings of Herodotus, and later Xenophon in the *Cyropaedia*.

Remarkably, some modern scholars, notably Peter Green, have regarded Herodotus's account as legendary, believing he mistranslated the Old Persian term, rendering *anusiya*, meaning companions or followers, as *anasa*, immortals. Even so, the existence of a ten-thousand-strong guard in the Achaemenid army is confirmed by other ancient writers, such as Xenophon, Arrian, and Polybius, and in the Sasanian era, 224 to 651 CE, a force known by the same name and marked by the same features, continuous training and leadership, superior equipment, is likewise recorded. The Battle of the Granicus, 334 BCE, was Alexander of Macedon's first encounter with the Iranian Immortal Guard, and on that day Alexander's life was seriously endangered twice, once by a sword blow and once by a spear thrust. But ultimately the flexibility and superior tactics of the Macedonians, using heavy cavalry, the *Hetairoi*, on the flanks, and the lack of coordination between Persian cavalry and the Immortal infantry, led to the Immortals being routed, and Alexander crossed into Iranian territory from the Dardanelles. At the Battle of Gaugamela, 331 BCE, the Immortals were again positioned at the heart of the Achaemenid army, alongside the scythed chariots, and fought fiercely, but the final defeat of Darius III, who fled the field, and his death at the hands of his own satrap, brought this legendary unit down as well. With the fall of the Achaemenid Empire, the name of the Immortals passed forever into legend in the annals of history, yet the role they played in organizing a permanent, professional army inspired those who organized armies in later centuries, from the Sasanians to the Ottoman Empire and the royal guards of Europe.

VI. The Parthian Empire: Heirs to Iran's Will, and the Invention of the Cataphract

Four centuries after the fall of the Achaemenids, 330 BCE, and the rise of the Seleucids, Alexander's successors in Iran, in the third century BCE, roughly 247 BCE, the Parthians, led by Arsaces, Ashk I, rose up from the northeast of Iran, present-day Khorasan province, and gradually gained mastery over the entire Iranian plateau and Mesopotamia, founding the Parthian Empire, 247 BCE to 224 CE. The Parthians regarded themselves as heirs of the Achaemenids and revived many military traditions, elite cavalry, archery, political traditions, kingship, satrapies, and cultural traditions, the Middle Persian language, the Zoroastrian faith. But what distinguished the Parthian army from the Achaemenid army was its reliance on mobility, mounted warfare, masterful long-range archery, and a capacity for deceptive, attritional combat. Unlike the Achaemenids, known for heavy infantry, spearmen in scale armor, scythed chariots, and dismounted archers, the Parthians relied above all on skilled cavalry, which required no level ground, and mounted archers, who possessed unmatched mobility. The Parthian army was built on two main pillars: heavily armored cavalry, cataphracts, who carried long spears, four meters, and were positioned at the heart of the army, to break enemy ranks, and lightly armed mounted archers, positioned on the flanks and rear of the army, to harass the enemy and fire from a distance. This dual structure, breaking ranks with the spear and striking with the sword on one hand, harassment and attrition by arrow on the other, was so effective that for centuries it kept the Parthians standing tall against two great neighboring powers, Rome in the west and the Kushans in the east, and the Romans were never able to fully defeat the Parthians and conquer Iran. The Parthians also relied on these same agile cavalry tactics against incursions by steppe nomads, the Scythians, the Yuezhi, from the northeast.

VII. The Cataphract: History's First Heavy Cavalry

Some scholars, including Zakaria Sitchin, among others, call the cataphracts the first knights in world history, predating the knights of medieval Europe. These horsemen, whose name, cataphract, from the Greek kataphraktos, means entirely armored, were so encased in heavy, multi-layered metal armor, of bronze, iron, and hammered leather, that even their horses were armored from head to foot, the horse's own armor made of metal plates or hardened leather. A covering of steel and leather was placed over the horse's head, a frontlet, its neck, an armored collar, and its body, armor extending to the knees. The image of a Parthian cataphract, wielding a spear four meters long, held with both hands, and a long, double-edged sword, charging at full gallop toward the enemy, struck terror into the Romans, since the shield and armor of the ordinary Roman soldier could not withstand the blow of this heavy spear, combined with the weight and speed of the horse, and the spear would pierce straight through a wooden shield and even segmented steel armor, the lorica segmentata. Cataphracts were designed to pierce the ranks of enemy infantry, especially Roman phalanxes, with their spear, and then continue hand-to-hand combat, amid the broken ranks, with their long sword, the spatha. The combined weight of armor, horse, and rider was such that if a cataphract fell from his horse, he could not get up alone and needed help. For this reason, cataphracts always went into battle alongside light cavalry, who supported them and prevented their fall, and infantry, to help them back onto their feet. In the Parthian battle formation, cataphracts were positioned at the center of the front, facing the heart of the enemy army, while light mounted archers took the flanks, for encirclement and harassment. On the battlefield, the cataphracts worked to split the enemy's ranks with their spears, while the light cavalry emptied their quivers and executed deceptive withdrawals, the Parthian shot. The Parthian cataphracts inspired the heavy cavalry of the Sasanians, the Immortal Guard, of Byzantium, the eastern Roman cataphracts, and the knights of medieval Europe, who wore full armor.

VIII. The Parthian Shot: Deception and Skill at the Height of Flight

The skill that set the Parthians apart from other cavalry forces, and even from the Achaemenids, was the Parthian shot. In this maneuver, whose very name attests to its Iranian origin, Parthian horsemen would feign flight from the battlefield, as though driven back by enemy pressure and relentless fire. While galloping their horses at full speed, in apparent retreat, they would suddenly twist their upper bodies backward at the waist. At that moment, holding the bow with both hands, as a standing archer would, they guided the horse using only pressure from their thighs and legs on its belly, without saddle or stirrup, which were invented later. An arrow fired this way carried not only the force of the bowstring's draw but also the forward momentum of the horse itself, so its speed and penetrating power exceeded that of an ordinary arrow fired from a standing position. The enemy, the Romans, pursuing and expecting to slaughter the fleeing horsemen, would suddenly find themselves under a hail of arrows from an unexpected direction, from behind, that they had not anticipated. This maneuver, feigning flight and then firing on the pursuers, caused confusion, heavy casualties, and demoralization among the Romans, and discouraged them from any reckless pursuit. The Parthian shot required years of practice, from childhood on horseback, and extraordinary balance, coordinating both hands with the horse's movement. Parthian horsemen rode small, hardy steppe horses known for their agility.

The Battle of Carrhae, 53 BCE, was the pinnacle of the art of the Parthian shot and an unprecedented defeat for the Roman Republic, which had never before suffered so humiliating a loss. On that day, the Romans, led by Marcus Licinius Crassus, who, together with Pompey and Julius Caesar, had formed the First Triumvirate of Rome, and who sought to plunder the treasures of the former Achaemenid lands, marched into Mesopotamia with a massive force, roughly forty-five thousand soldiers, including four thousand cavalry and four thousand archers. But Surena, the Parthian general, with a far smaller force, ten thousand horsemen, of whom a thousand were cataphracts and nine thousand mounted archers, trapped the Romans on the barren, waterless plains of Carrhae, near the city of Harran in present-day Turkey. The Parthian mounted archers opened fire from a distance, fifty to one hundred meters, and refused to engage in close combat. To escape this hail of arrows, which inflicted ever greater casualties by the day, Crassus sent his son Publius on a charge with 1,300 Gallic cavalry, 500 archers, and eight cohorts of spearmen; but the Iranian cataphracts, the second part of Surena's force, suddenly charged them from behind the hills, targeting the lightly armored Gallic horsemen with their long spears. Publius was killed, and his head was mounted on a spear, and the Roman soldiers, now surrounded, exhausted in the dry, dusty desert, could not hold out. In the end, Crassus himself was killed during sham negotiations, his head cut off and sent to the Parthian king, and a third of the Roman army, roughly twenty thousand killed and ten thousand captured, was destroyed or taken prisoner. This defeat shook Rome's prestige and showed that a nimble, archer-based cavalry force, Parthian, could overcome a heavily armed infantry force, Roman, given strategic patience and the use of deceptive tactics, the Parthian shot. The Battle of Carrhae became the model for Parthian-style warfare, guerrilla cavalry combat, for centuries to come.

IX. The Legacy of the Cataphracts and the Parthian Shot in Later Generations

Although the Parthian Empire fell in the third century CE, 224 CE, at the hands of Ardashir Babakan, founder of the Sasanian dynasty, the legacy of the cataphract and the Parthian shot never grew old. The Sasanians, who regarded themselves as heirs, both militarily and culturally, of both the Achaemenid and Parthian dynasties, and took pride in reviving the glory of Iranshahr, established an institution called the Aswaran, the free-born knights, which continued the tradition of the Parthian cataphract while also embodying an ideal of the splendor of the army of Iranshahr. In the Sasanian army, the Aswaran, sometimes called *clibanarii*, formed the most elite strike force, whose horses and riders alike were covered in metal armor, from head to toe, and who carried long spears, four to five meters. The Sasanian Aswaran were widely renowned and played a decisive role in the wars between Iran and the Eastern Roman Empire, Byzantium, from the third to the seventh centuries CE, and later against Arab invaders in the seventh century, though ultimately the Arab Muslims triumphed over the heavily armored Aswaran through mounted archery tactics, borrowed from the Parthians, and superior mobility. The Parthian shot, too, spread beyond Iran's borders. The Mongols and the Turks, who later converted to Islam, employed this same tactic, firing while in retreat with a composite bow, in their campaigns, conquering territory from China to Europe, Poland, Hungary, in the thirteenth century. This technique then made its way to Europe, through contact with the Mongols and later the Ottomans, and was seen in the medieval period among certain armored horsemen and knights, German, Polish, the Hussars, and Hungarian, though its importance declined with the advent of the firearm. In this way, what began as an Iranian technique, and before that, a Scythian one, became a universal body of knowledge on the battlefield, and it still lives on today in modern equestrian displays.

X. Chapter Summary: The Continuity of Two Dynasties in a Single Tradition

Chapter Ten has shown that the Achaemenid and Parthian armies both arose from a single ancient Iranian tradition, resting on cavalry, archery, and discipline, and that only their military doctrines evolved differently in response to different threats, in the west and the east. The Achaemenids, with their heavy infantry, Persian and Median spearmen, and their scythed chariots, demonstrated the art of conquering great empires, Media, Lydia, Babylon, Egypt, and administering a continental empire, drawing on ethnic diversity, Egyptians, Phoenicians, Greeks, Indians, to strengthen the army. The Immortals, as the world's first standing, professional army, apart from small Egyptian guards, stood as a symbol of Achaemenid power. The Parthians, by contrast, relying on an unconventional cavalry, combining heavy cataphracts and light Parthian archers, forged a new approach to asymmetric, attritional warfare that remained effective on the battlefield for two centuries after their own fall, and that brought the Romans, who relied on heavy infantry, to the brink of collapse. Between these two, the Immortals continue to shine as the symbol of a permanent, professional army in ancient Iran. In the next chapter, Chapter Eleven, Gunpowder and the Collapse of the Logic of Fortification, we will see how gunpowder and the firearm shattered this ancient tradition of cavalry and spearmen forever and opened a new age of violence at a distance. It is as though, a thousand years after the Parthians, Iranians once again placed their trust in the strength of fortresses and fortifications, such as the Great Wall of Gorgan and the fortifications of Mesopotamia; but this time it was not the cataphract's shield, nor a stone wall, but gunpowder and Ottoman cannon at Chaldiran, 1514, that forever transformed the balance of power in West Asia.

Chapter 11

Siege Engines and Fortifications: The Millennia-Long Battle of Attacker and Defender

The Pivotal Moment: August 6, 1232 BCE, the Walls of Troy, Anatolia

For nine years the Greek army had knelt before the impregnable walls of Troy. Every morning, Trojan soldiers could be seen atop the towers, loosing their arrows at the besiegers. The Greeks had tried everything: sword, spear, arrow, and had repeatedly battered the gates with rams. But the walls of Troy, so massive and enduring that later historians attributed their construction to the gods Apollo and Poseidon, held firm every time. In this ninth year of the siege, Odysseus, the most cunning of the Greek commanders, had a plan. The soldiers withdrew. Troy breathed a sigh of relief. But hours later, the gates opened and a great wooden horse was brought into the city, a gift from the Greeks to Athena, goddess of wisdom. At night, in total darkness, forty Greek soldiers emerged from the horse's belly, opened the gates for the army hidden outside the walls, and Troy burned. The legend of Troy proclaims a simple truth: no wall stands forever safe against human cunning and technology.

Eyewitness testimony, a mythic account of the siege of Troy as told by Homer in the Iliad, rendered here in translation rather than as a direct quotation, recalls the moment the gates were opened, not knowing what lay hidden in the wooden horse's belly, the Greeks' gift to Athena, a symbol of their victory, and how, in the night, the horse's belly was opened and death poured out.

The Birth of Siege Warfare: From Primitive Fortifications to Great Fortresses

With the establishment of agriculture and the rise of the first cities in the Neolithic, roughly ten thousand years ago, humans confronted a wholly new concept for the first time: the wall. Portable, temporary camps were no longer sufficient. Cities were enclosed by stone or mudbrick walls to protect their inhabitants and grain stores from the raiding attacks of neighboring tribes. The oldest known wall in the world was found at the site of Jericho in Palestine, roughly 8000 BCE. This wall, 3.6 meters high and 1.8 meters thick, built of stone, had a stone tower eight meters high, nine meters in diameter, likely used as a watchtower and firing platform. The birth of the wall brought with it the birth of siege warfare. Attackers could no longer take a city through a single direct, surprise assault. They were now forced either to besiege a city for months or years until hunger forced its surrender, or to invent tools for breaking through walls. In this way, the ancient rivalry of shield and spear began on a far larger scale: every time walls grew taller and thicker, attackers built larger catapults and heavier battering rams. The defensive fortifications shaped by this rivalry evolved from the mudbrick walls of Jericho in Palestine, eight thousand years ago, 3.6 meters high and 1.8 meters thick, to the immense ramparts of Babylon, six hundred years before Christ, twenty-five meters wide with hundreds of watchtowers.

The Battering Ram: The First Mechanical Weapon for Breaking a Wall

The battering ram was the simplest, and at the same time most effective, siege weapon for bringing down wooden gates and stone walls. Its principle is simple: a great tree trunk, ten to thirty meters long, one end of which was capped with a hook or a ram's head made of bronze or iron. This trunk was either dragged back and forth by soldiers with ropes and driven against the gate, or suspended inside a covered wooden structure, called a tortoise, or vinea, so that soldiers, sheltered beneath a roof protected from the defenders' arrows and stones, could set it in motion.

The earliest battering rams were simply heavy trunks carried by a group of soldiers and driven against the gate with all their strength. But this method was dangerous; the soldiers, while carrying and swinging the trunk, were defenseless against archers and stone-throwers atop the wall. To solve this problem, the covered ram, the testudo ram, was developed: an immense wooden structure mounted on four wheels, with a sloped deck and roof, usually covered in wet leather or metal for resistance against fire. Inside this tortoise, the trunk hung suspended, and soldiers drove it forward and back with relative safety. The oldest depictions of the battering ram appear in the tomb paintings of ancient Egypt, the Old Kingdom period, roughly 2500 BCE. The Assyrians, 900 to 600 BCE, mounted colossal battering rams, requiring forty to fifty men to move, on wooden wheels and placed them within siege towers that rose

to the height of a city's walls. The Romans, too, perfected the battering ram; Roman rams often had an iron head shaped like a ram's head, called an aries, and were housed within large wooden structures covered in wet hide for fire resistance. At the Roman siege of Jerusalem, 70 CE, Roman battering rams brought down the city's massive walls after several weeks of pounding.

Eyewitness testimony, from the margins of the siege of Jerusalem, 70 CE, as told by Josephus Flavius, the Jewish-Roman historian, rendered here in translation, recounts how the Romans set a massive ram in motion; each time the iron ram struck the wall, the ground shook and dust filled the air; the defenders hurled great stones and boiling pitch down upon it from atop the wall; but the wooden housing was covered in animal hide and repelled the fire; the blows of the ram grew stronger by the day; and finally, after three days, the wall cracked and collapsed, and the sound of Roman cheering mingled with Jewish cries of terror as the city fell.

The Siege Tower: An Elevator of Death Toward the Wall

The siege tower, called a belfry in ancient sources, was a device for delivering soldiers to the top of an enemy's high walls. Unlike the battering ram, which struck the wall from below, the siege tower struck from above. Siege towers were immense wooden structures, usually mounted on four large wheels, sometimes reaching a height of more than thirty meters, the height of a ten-story building. Their height was built to match, or exceed, the tallest wall of a city. The siege tower had multiple levels, each filled with archers and spearmen. Its outer surface was covered in wet, hammered animal hide for resistance against arrows and fire, and was sometimes clad in metal. During an intense siege, the tower was rolled up to the wall and a movable gangplank was dropped from the top of the tower onto the wall. Soldiers crossed it at once and seized the wall.

The earliest evidence for the use of siege towers comes from ancient Egypt, the Twenty-Fifth Dynasty, roughly 720 BCE, and Anatolia, the Bronze Age. The Assyrians used siege towers in the ninth century BCE. The Greeks and Romans, too, developed mobile towers in the fourth century BCE. The largest siege tower in history was the Helepolis, built by Demetrius Poliorcetes at the siege of Rhodes, 305 BCE. This tower was so massive, forty meters tall and 160 tons, that it required 3,400 soldiers to move it forward and back, and each of its sides was defended by a team of two hundred men. Even so, siege towers had major drawbacks: they were slow and costly to build, their immense weight caused them to become stuck on uneven or muddy ground, and they fell easy prey to enemy fire and catapults. Siege towers were often the first target of an enemy's catapult fire, since their enormous bulk was visible from a distance, but they themselves also carried archers atop them to return fire.

Throwing Machines: Colossal Catapults and the Science of Destruction at a Distance

If the battering ram and the siege tower required closing the distance to the wall, catapults were weapons of distance, built to hurl large stones, giant bolts, disease-infected animal carcasses, and even fire-bearing hives, an early Chinese incendiary device, from behind walls and hills. Catapults are divided by their power source into two main categories.

First, the torsion catapult, the onager, perfected by the Greeks in the fourth century BCE and later by the Romans, which used twisted fibers, such as animal sinew, horsehair, or linen rope, to generate force. The ropes were tightly twisted to store torsional energy, then the catapult's arm was drawn down to ground level and locked in place. Releasing the lock sent the stored torsional force snapping the arm upward with incredible speed, hurling a stone, thirty to fifty kilograms, with tremendous force, up to five hundred meters, toward the enemy's walls. The Romans called this type of catapult the onager, the wild ass, because of the violent kick it delivered to the ground upon firing. The most famous type of torsion catapult was the ballista, designed to launch giant bolts, up to a meter long, resembling a spear, or shorter, highly accurate arrows, resembling a colossal horizontal crossbow.

Second, the counterweight trebuchet, the most advanced and powerful type of catapult, which spread across Europe and the Middle East in the twelfth century CE, the era of the Crusades. Rather than human power or torsion, this type of catapult used a heavy counterweight, usually a box filled with stone or lead, weighing between five and twenty tons, to launch its arm. The weight sat on one side of the pivot and the projectile on the other. Releasing the lock caused the weight to fall, driving the long arm upward with tremendous acceleration. The result: a projectile weighing one hundred to 160 kilograms, and sometimes up to three hundred kilograms in the heaviest trebuchets, struck an enemy's walls at very high speed and an effective range of two to three hundred meters, with a maximum range of up to five hundred meters.

The advantage of the counterweight trebuchet lay in its far greater accuracy, since its force was constant and did not depend on soldiers' fatigue, its immense destructive power, a 150-kilogram projectile could bring down a two-meter stone wall, and its capacity for sustained fire. The counterweight trebuchet was known as the supreme weapon of the medieval period and remained in use until the advent of gunpowder cannon in the fifteenth century.

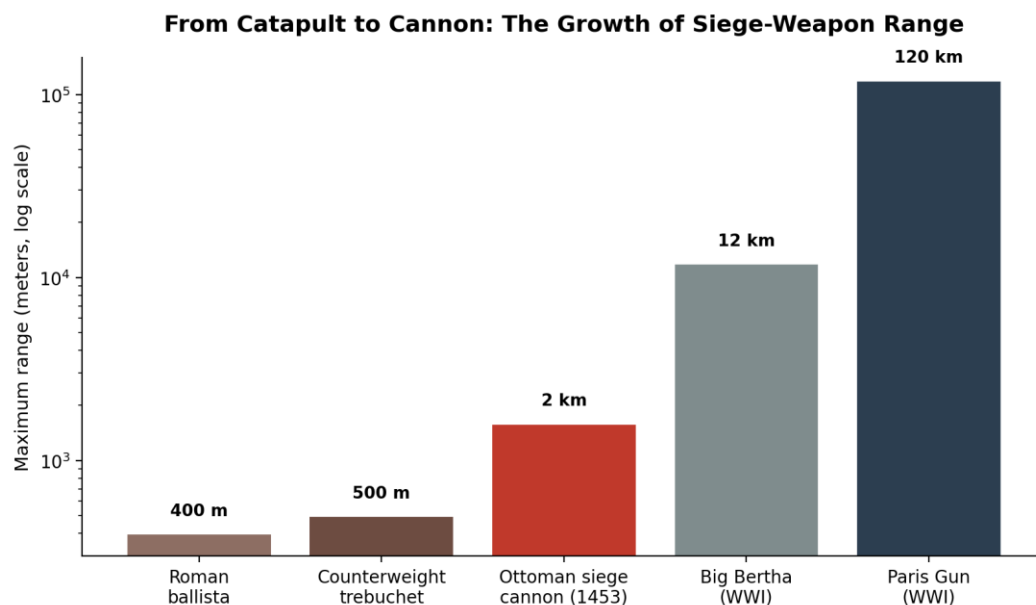


Chart: The growth of siege-weapon range from antiquity to the First World War, shown on a logarithmic scale (author's diagram, illustrative).

Eyewitness testimony, from the margins of the siege of Beauvoir castle, 1216, France, as told by Robert de Clari, a chronicler of the Crusades, rendered here in translation, recalls how their forces built an immense catapult they called Malvoisin, meaning bad neighbor, which each day rained stones weighing a ton upon the defenders; the stones were so large they shattered the castle wall like paper; and after four days of bombardment, no point of the wall remained intact, and the defenders were forced to surrender.

Defense Against Siege: Fortifications, Moats, and Defensive Machines

Siege warfare was not reducible merely to battering down a wall. It was a complex art combining engineering, deception, and psychological endurance. Defenders, too, improved their fortifications throughout history. Simple rectangular walls, with square towers, common in Egypt and Mesopotamia, had blind spots, points that defenders atop the towers could not fire down upon at the base of the wall. Defenders dug deep moats around a city's walls, sometimes filling them with water, to prevent siege towers and battering rams from approaching the wall. Attackers were then forced to fill the moat with earth, stone, wood, and sometimes even the bodies of their own fallen comrades. In the medieval period, concentric castles were designed with round and semicircular towers to eliminate blind spots. Dry or water-filled moats, iron gates, the portcullis, and sloped walls, to deflect a catapult's projectile, were among the other defensive innovations.

Beyond passive fortifications, defenders also used active weapons. Counter-fire: archers fired at attackers through arrow loops in towers and walls, while attacking archers and slingers fired at defenders atop the wall from behind large shields, the pavise, or from siege towers. Undermining: defenders dug counter-mines to meet the enemy's tunnels underground, while attackers, from the other side, dug tunnels beneath a city's wall, using pick and shovel, and then set fire to the wooden props supporting the wall. Fire-bearing and biological projectiles: defenders atop the wall hurled great stones, boiling pitch, boiling water, and even beehives down upon attackers, while attackers, in turn, catapulted clay vessels filled with naphtha, Greek fire, or the carcasses of plague-infected animals into the city.

Famous Historical Examples of Siege Warfare

The siege of Troy, roughly 1200 BCE, legendary, though grounded in the archaeological excavation of the Troy layers: after ten years of unsuccessful siege, the Greeks took the city through the ruse of the wooden horse, together with ladders, fire, and the enemy's confusion. This siege became a lasting symbol of psychological warfare and deception in history.

The siege of Tyre, 332 BCE, by Alexander of Macedon: the city of Tyre was an island with massive stone walls, forty-five meters high. Alexander, using colossal siege towers, fifty meters tall, battering rams, and catapults, and, most importantly, by building a land causeway eight hundred meters long, using stone and timber, that connected the island to the mainland, took the city after seven months of siege and hand-to-hand fighting.

The siege of Malta, 1565, by the Ottomans: forty thousand Ottoman soldiers, with two hundred ships and immense artillery, against six thousand Maltese knights and soldiers. Despite the use of catapults, cannon, and tunneling, the Ottomans could not take Malta's star-shaped fortifications. This region, with its short, thick walls and triangular bastions, known as the *trace italienne*, remained safe from Ottoman artillery. The siege of Malta was the first great victory of gunpowder-age fortification against direct assault.

The siege of Constantinople, 1453, by the Ottomans: a combination of the largest cannon in history to that point, the Basilic of Urban, firing a 500-kilogram ball, the battering ram, the catapult, and tunneling. The Ottomans hauled their ships overland, on wood and oil, from the Bosphorus strait to the Golden Horn to complete the naval blockade. The Theodosian Walls, after a thousand years of standing firm, finally collapsed under the weight of the cannon, and Constantinople fell. The contest between the walls of Constantinople, the Theodosian Walls, and Ottoman cannon was, in its own way, a masterpiece of engineering and technology on both sides. The greatness of the cannon lay in the fact that, instead of fifty-kilogram stones, they hurled 500-kilogram balls, far beyond anything seen in earlier years.

The greatness of the walls lay in the fact that, despite such projectiles, they held out for seven weeks.

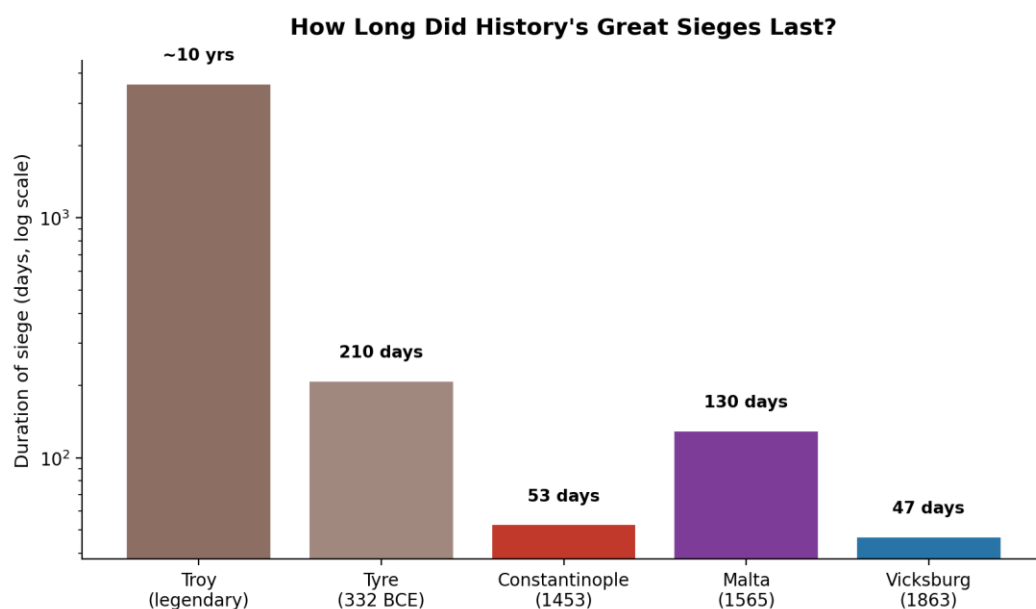


Chart: The duration of several historically significant sieges, log scale (author's diagram, illustrative).

Eyewitness testimony, from the margins of the siege of Constantinople, 1453, as told by Georgios Sphrantzes, the Byzantine historian, rendered here in translation, describes clouds of smoke and dust so thick that the sun could not be seen even at midday; the cannon stones shattered the wall to pieces, and the defenders rebuilt it by night with stone and brick; but the wall grew shorter every day; on the final day, the sultan ordered a general assault; they defended every span of the wall with sword and spear; but when the Ottoman banner rose over the tower of San Romano, they understood that their empire had fallen forever.

Chapter Summary: In Praise, and in Mourning, of Walls

Chapter Eleven has shown that siege warfare, the assault upon, and the defense of, fortified cities, was among the most complex and costly forms of conflict in human history. The battering ram, with its simple but devastating mechanical power, and the siege tower, with its own ambition to overcome height, were both remarkable human innovations for overcoming nature, the wall. Catapults, from the ballista and the onager to the colossal trebuchet, were history's first war machines to apply the laws of physics, leverage, torsion, and gravity, to overcome stone fortifications. The rivalry between attackers, who sought ever stronger battering rams and ever larger catapults, and defenders, who sought ever taller, thicker walls and new fortifications, was the driving engine of innovation in architecture and military engineering for more than five thousand years. But in the end, with the advent of gunpowder and great cannon, examined in the next chapter, the battering ram and the catapult gradually left the battlefield. Even so, fifty years of siege warfare with early cannon showed that even cannon alone could not easily overcome modern fortifications, and the star-shaped fortifications built at Malta and elsewhere marked the rebirth of defense. The principles of siege warfare, cutting supply lines, bombardment from a distance, tunneling, and the use of layered fortifications, remain part of military operations to this day.

Chapter 12

Gunpowder and the Collapse of the Logic of Fortification

The Chinese Elixir That Shook the World

In the mountains of southern China, where Taoist monks searched for an elixir of immortality, a mixture of sulfur, charcoal, and saltpeter, potassium nitrate, was placed in a crucible. The goal was to find the medicine of eternal life. But when the heat reached a certain point, a spark flared and a burst of smoke, fire, and sound leapt from the crucible. This was not the first time someone had encountered this combination, but this time, one of the experimenters noticed something: this small explosion carried a force that could move objects. He did not know that he held in his hands the key to a fundamental transformation of war. We do not know the exact year gunpowder was invented, likely the ninth century CE, in the late Tang dynasty. But the earliest written text describing the formula for gunpowder dates to 1044 CE, in the book *Collection of the Most Important Military Techniques* by Zeng Gongliang. There, three different formulas for gunpowder are given, in which the proportion of saltpeter varies between fifty and seventy percent. The Chinese called this substance *huo yao*, fire medicine. They discovered that the high ratio of saltpeter, a strong oxidizer, to sulfur and charcoal, the fuel, determined the power of the explosion. Gunpowder brought about a fundamental revolution in the history of violence. For the first time, the power to kill was entrusted not to human muscle but to a chemical reaction. Strength of arm, skill in archery, and the hardness of a sword no longer decided anything. Now anyone who could confine gunpowder within a tube and place a ball at its mouth could bring the mightiest armored knight down from his horse. Gunpowder erased the line between strong and weak in a single moment. A child could, with a spark, set off a cannon capable of shattering a ton of armor. This unprecedented democratization of violence marked the end of the age of knights, though the knights themselves would not learn of it for another century.

From Fireworks to Cannon: Gradual Evolution East and West

The first Chinese gunpowder weapon was the fire lance, a bamboo tube filled with gunpowder and bound to the head of a spear. When the gunpowder ignited, flame, sparks, and smoke burst from the mouth of the bamboo tube. This weapon did not kill the enemy, but it terrified him. Horses bolted, soldiers fell back, and their armor, though not pierced, grew so hot that wearing it became unbearable. In Chinese naval battles, fire lances were used to set an enemy ship's sails alight. But before long, the Chinese realized that if small pieces of stone or metal were placed inside the tube alongside the gunpowder, those fragments would burst from the tube at high speed and strike the target. This was history's first firearm: a shrapnel-launching tube, or bamboo hand cannon. Its range was short, roughly twenty meters, its accuracy poor, and the tube itself was prone to bursting, since bamboo is weak against pressure. But its psychological effect was undeniable. An enemy who saw a cloud of fire, shrapnel, and smoke rushing toward him, even without being harmed, would flee. Fear of the unknown was, at times, more lethal than the weapon itself.

The Chinese soon discovered that a metal tube, bronze or cast iron, offered far greater resistance. Early Chinese cannon, called *zhan*, were cast from iron and fired stone balls. In a battle in 1232 CE, Chinese forces used iron cannon against the Mongols. The Mongols, unfamiliar with gunpowder technology, were terrified by the noise and destruction. But the Mongols, too, quickly learned. They captured Chinese craftsmen and used them to make cannon and gunpowder of their own. By the late thirteenth century, the Mongols had carried gunpowder westward. In 1260, at the Battle of Ain Jalut in Palestine, the Mamluks of Egypt encountered Mongol hand cannon for the first time in West Asia. Although the Mamluks won that battle, they quickly realized they too needed to master this dangerous technology. Sultan Baybars ordered captured Chinese and Mongol craftsmen to build cannon for the Egyptian army. In this way, gunpowder entered the Islamic world. Europe came to know gunpowder later than the Islamic world. The first definitive reference to gunpowder in Europe appears in the writings of Roger Bacon, the English friar, in 1267. Bacon described the formula for gunpowder in coded language, with great caution, so that the secrets of fire would not fall into the wrong hands. Of course, they did. European monks and alchemists quickly reconstructed the formula, and within a century, great iron cannon were being cast in European workshops.

The Cannon: Killer of Medieval Walls

The medieval period in Europe was an age of castles: thick stone walls, up to ten meters, watchtowers, water-filled moats, and iron gates. A besieging army spent months or years either starving a castle into submission or battering its walls with catapults and rams. Colossal trebuchets, hurling stones weighing a ton, could strike a wall dozens of times a day. But walls often held. Examples such as the walls of Constantinople, the Theodosian Walls, had withstood every kind of siege for a thousand years. The cannon upended this equation. The first European cannons were called petards or ribauldequins, short iron or bronze tubes mounted on wood, firing stone balls. Their range was short, fifty to a hundred meters, and their accuracy negligible. Early gunpowder, corned powder, was weak and its balls flew erratically. But if a ball struck a wall, it broke off a piece of stone and it crumbled. A few dozen balls, over the course of a single day, could accomplish what catapults could not achieve in a month. Most important of all, the cannon produced a terrifying noise and a cloud of smoke that shattered the morale of defenders. Defenders, who for centuries had grown accustomed to the safety of walls, suddenly discovered that walls were no longer an absolute refuge. In 1453, Sultan Mehmed the Conqueror, to take Constantinople, hired a Hungarian cannon founder named Urban. Urban cast a cannon eight meters long and twenty tons in weight, equal to the weight of forty horses, that fired stone balls weighing five hundred kilograms. This cannon, later called the Basilic, brought down the Theodosian Walls with twenty-one shots. The impact of each ball was such that the ground shook and the sound could be heard a hundred kilometers away. Constantinople fell, and with it, the medieval world came to an end. The Byzantine Empire, the Eastern Roman Empire, which had stood for a thousand years, collapsed. The cannon destroyed not only stone walls, but the very mindset of defense. No fortress was safe any longer. Kings and rulers discovered that the best defense was no longer hiding behind a wall, but firing first. A new arms race began: whoever had the bigger cannon, the faster ball, and the more durable barrel, won. Cities that until yesterday had rested easy behind their sturdy walls suddenly had to rebuild their fortifications in a new style, the trace italienne, star-shaped. These fortifications, with their short, thick walls and sharp angles, were designed to deflect a cannonball and were themselves supported by defensive artillery fire from neighboring walls. But their cost of construction and upkeep was tens of times greater than that of the old walls, and only wealthy states could afford them.

The Handheld Firearm: The Democratization of Fire

Alongside great cannon, handheld gunpowder weapons also evolved. The matchlock became common in Europe in the late fifteenth century. Its mechanism was simple: a lever brought a slow-burning match, a cord soaked in saltpeter solution, down onto the powder in the priming pan. This ignited, and through a small touch-hole, set off the main charge inside the barrel. This mechanism reduced firing from a two-step process, lighting the match and taking aim, to a single motion, pulling the lever. This gun was heavy, five to six kilograms, short-ranged, fifty meters effective, and slow, one shot per minute. Its powder grew damp and failed in rainy weather. Its match could be seen at night, giving away the shooter's position. But against the English longbow, it had one great advantage: it was easy to train. A skilled archer had to practice from childhood to build powerful arms and learn accurate marksmanship. Years of practice were needed to reach a rate of fire of ten arrows per minute. But a musketeer could be trained in a few weeks. Ordinary peasants, who until yesterday had feared the horse and sword of a knight, could now stand in ranks, pull a trigger, and bring down the most heavily armored rider. This democratization of violence had profound social consequences. Knights, who had ruled as the dominant military class for centuries, were suddenly rendered useless. Heavy armor, once a barrier against arrow and sword, was ineffective against a lead ball. A lead bullet traveling at three hundred meters per second passed easily through thick steel plate, up to four millimeters. Modern tests show that even the armor of the Napoleonic era, up to six millimeters, could not stop the bullets of the firearms of that time. Nobles who had defined their entire identity through mounted combat and swordsmanship were now killed by a bullet from the hand of a nameless foot soldier. Psychologically, the gun increased psychological distance. Unlike the spear, which was still close, or the sword, which required direct contact, the gun allowed a shooter to bring down his victim from a hundred meters away, without seeing his face. The sound of the blast and the smoke blurred the scene. Death became more abstract and easier to bear.

The Military Revolution and the Birth of the Modern State

Military historians call the period from 1500 to 1700 CE the Military Revolution. In these two centuries, three fundamental changes occurred. First, a dramatic increase in the size of armies. With the gun, years of training were no longer necessary. Any village man, with a few weeks of instruction, could become an acceptable soldier. The French army grew from twenty thousand men in 1500 to three hundred thousand in 1700. This growth required enormous logistics, supplying food, ammunition, clothing, and pay, and an efficient bureaucracy for registration,

training, and distribution. States were forced to create specialized military institutions and centralized administration. Second, the concentration of violence in the hands of the state. Cannon and guns were expensive. A single mid-sized bronze cannon in the sixteenth century cost as much as ten years of a knight's wages. A matchlock gun, still handmade in the sixteenth century, cost as much as several months of a laborer's pay. Only centralized states with an efficient tax system could produce and distribute thousands of guns. Kings who had once depended on loyal knights for war now had standing, mercenary armies loyal only to their pay. In this way, powerful nation-states, such as the France of Louis XIV, Tudor England, and Tsarist Russia, were born. By contrast, local nobles who could not afford cannon and guns were, one by one, disarmed and made subject to central power. Third, new fortifications, the *trace italienne*. Against the cannon, tall, thin walls were useless. Italian military architects designed star-shaped fortifications: short, thick walls, up to thirty meters at the base, with sharp angles that deflected cannonballs, and which were themselves covered by musket fire from neighboring walls. These fortifications were extremely expensive to build and maintain, the cost of building one *trace italienne* was ten times that of an ordinary wall, and only wealthy states could build them.

The Battle of Chaldiran (1514): Sword Against Gunpowder

On August 23, 1514, on the plain of Chaldiran, in present-day northwestern Iran, two armies drew up against each other. On one side, the Safavid army of Iran, led by Shah Ismail I, forty to fifty thousand soldiers armed with sword, spear, and bow. On the other, the Ottoman army, led by Sultan Selim I, one hundred to 120 thousand soldiers, equipped with thousands of guns and hundreds of cannon of various calibers. Shah Ismail, who had won a string of victories through the traditional cavalry tactics of the Qizilbash, with sword and bow, distrusted the power of cannon and gun. The Qizilbash motto was death to the mind of the cannoneer, and they believed that individual courage and the blow of the sword surpassed the cold fire of gunpowder. The Battle of Chaldiran is a historical turning point in several respects. First, the Ottomans positioned their cannon behind chained wagons, to prevent a Safavid cavalry charge. Second, Janissary musketeers, the Ottoman professional infantry, were arrayed in several ranks, one behind another, executing volley fire. Third, the Qizilbash, with extraordinary courage but with no artillery or gun support whatsoever, charged the Ottoman ranks. The battle was a catastrophe for Iran. The Qizilbash cavalry was halted by a hail of cannon and gunfire before ever reaching the enemy's ranks. Horses bolted, riders fell to the ground. Shah Ismail, who was nearly captured on the battlefield, barely escaped with his life. Qizilbash casualties exceeded five thousand men, against roughly two thousand Ottoman losses. The Battle of Chaldiran showed that the sword and individual courage were no match for the organized fire of gunpowder and cannon. From this point on, Iran too was forced to move, however reluctantly and with delay, toward adopting firearms and forming artillery units. Chaldiran was one of history's bitter lessons, proving that technological progress changes the rules of war, and that those who fail to grasp that change are doomed to defeat.

The Firearm and the Shift in the Global Balance of Power

Gunpowder divided the world into two parts: countries that gained the technology of cannon and gun, and countries that did not. In the sixteenth century, the Portuguese and the Spanish, with ships armed with cannon, crossed the oceans and built vast empires in Asia and the Americas. At the Battle of Cajamarca, 1532, in Peru, Francisco Pizarro, with 106 infantry and sixty-two cavalry, armed with guns and light cannon, crushed the eighty-thousand-strong army of the Incas. Not through courage, but through terror and heavy casualties inflicted by gunpowder fire. The Incas had never before encountered the sound of exploding cannon, smoke, and shrapnel. Their horses, unknown to them as well, and their ranks, bolted and fell apart. This technological gap annihilated tens of thousands of years of military evolution in a single day. By contrast, the Ottoman Empire, which rapidly cast great bronze cannon, was able to take Constantinople and advance as far as Vienna. Safavid Iran and Mughal India, too, adopted artillery and built powerful empires. But countries that resisted gunpowder, such as the indigenous peoples of the Americas, Australia, and Africa, were either destroyed or fell under colonial rule. In Asia, China, despite having invented gunpowder, never underwent a military revolution and remained vulnerable to Western artillery until the nineteenth century. Environmentally, the extraction of saltpeter was a disaster. Saltpeter formed naturally in the soil of caves and old ruins, from the decomposition of organic matter. But as demand grew, saltpeter miners began digging up farmland and tearing down old walls. Sulfur, too, was extracted from volcanic mines, itself a source of heavy pollution. Iron smelting for cannon accelerated deforestation. Every kilogram of smelted iron required twenty kilograms of charcoal, and every kilogram of charcoal came from ten kilograms of wood. In other words, a single twenty-ton cannon was the product of the destruction of four hundred thousand kilograms of wood. This unprecedented figure devastated Europe's forests on a

massive scale. Culturally and socially, gunpowder gave war a new sound. The noise of exploding cannon and gunfire, which had not existed before in nature, echoed across battlefields for the first time in history. Soldiers who survived gunpowder battles often suffered from shell shock, an early form of PTSD. Military surgeons of the sixteenth century wrote that some soldiers, for months after battle, would writhe and collapse to the ground and involuntarily urinate at the sound of a loud noise, thunder, or a knock at the door. This is history's first description of post-traumatic stress.

A Fragment of History

From the margins of the Battle of Cerignola, 1503, retold in the voice of a Spanish soldier, rendered here in translation: we Spanish musketeers stood in rank. The commander shouted, fire! A hundred guns fired at once. The smoke was so thick I could not see the enemy. But I could hear the sound of balls striking the armor of the French knights, a sound like rain on a metal roof. When the smoke thinned, we saw fifty knights fallen to the ground. The horses had bolted. The knights tried to rise, but their heavy armor held them down. We fired again. The man shooting at me from fifty meters away, I never saw his face. He was only a target. A point. This distance the weapon gives us makes killing easy. I was no longer a soldier, but a butcher. From the memoirs of an unnamed Spanish soldier.

Chapter Summary

Chapter Twelve has shown that gunpowder was not merely an explosive substance, but the force that shattered the old order of war. Walls were no longer safe. Armor no longer protected. Individual skill, swordsmanship, archery, was rendered worthless. War shifted from a battle of elites to a slaughter of the masses. Centralized states, capable of mass-producing gunpowder and cannon, grew powerful, and local nobility were disarmed. The Battle of Chaldiran, 1514, was a vivid example of this transformation: the traditional Safavid army, reliant on sword and cavalry, was shattered before Ottoman artillery and musketeers. At the global level, access to gunpowder drew the line between great powers and tribal societies. Countries that failed to adopt this technology were doomed to destruction or colonization. Gunpowder was history's first globalizing weapon; from China to Europe to the Americas, no corner of the world was spared its effect. But gunpowder, too, had its own limitations: poor accuracy, a low rate of fire, vulnerability to weather, moisture, and the need for constant cleaning, as powder residue fouled the barrel. These limitations pushed humans toward the next innovations, the percussion cap, the unified cartridge, the bolt-action rifle. The next chapter,

The Rifle, Modern Infantry, and the Death of Individual Skill, is devoted to these innovations.

PART THREE

The Age of Gunpowder and the Military Revolution

Chapter 13

The Rifle, Modern Infantry, and the Death of Individual Skill

The Pivotal Moment: April 28, 1503, the Plain of Cerignola, Italy

The sound of dry, successive blasts tore through the calm of dawn. Battalions of French knights, armored from lance-tip to horse-hoof, with long spears and banners raised, charged toward the Spanish lines. This was a classical assault, the very kind that had won the French victory for a hundred years. Hooves pounded the stony ground and thick dust rose over the plain. But this time, something else was at work. Out of the dust, streams of fire and smoke leapt from the short barrels of Spanish musketeers. Foot soldiers, peasants until only yesterday, stood in tight ranks, bringing the match down onto the powder pan with a simple lever. Louis de la Trémoille, the young and bold French commander, watched with his own eyes as his comrades fell from their horses one after another. Not sword blows, not long spears, not even the great names behind them. A single small lead ball, leaped from the barrel of a peasant fifty paces away, was enough to destroy fifty years of chivalric training in the blink of an eye. Moments later, Louis himself, struck in the chest by a ball, fell from his horse. The French army was shattered. One Italian survivor later wrote that courage no longer meant anything, that a child could kill the mightiest man with the press of a single finger. This moment was the birth of the age of the gun, the age of the death of individual skill.

Eyewitness testimony, from the margins of the Battle of Cerignola, 1503, rendered here in translation, recalls watching the armored French knights cut down like wheat; the Spanish gunners did not even look at their faces; they only poured powder, set the ball, and pulled the trigger; and each time the sound rang out, another French nobleman fell to the ground; from that fear of the gun, the writer says, he never again drew close to a foot soldier carrying a pistol, from Francesco Guicciardini, the Italian historian.

From the Weapon of Elites to the Tool of Ordinary People

Before the gun, war was skill-driven. An English archer, to reach a rate of fire of ten arrows a minute with the longbow, had to practice from childhood until the muscles of his back and arms grew strong enough to draw a bow with a pull of seventy to eighty kilograms. A Japanese swordsman, a samurai, spent years in meditation, kata, and dueling to reach a level of mastery. These skills had made war an elite domain. Only those with the time and resources for training, nobles, samurai, knights, could be effective warriors. But the gun upset this equation. An illiterate peasant could be trained within two weeks to load a matchlock, take aim, and fire. Though his accuracy was initially poor, within a dense formation, individual accuracy lost its importance. What mattered was the volume of collective fire. This transformation is called the death of individual skill. From this point on, courage, agility, and individual experience faded before the volume of fire and collective order. A disciplined regiment of infantry, with coordinated volleys, could slaughter an enemy's finest knights before they ever reached the front line. The Battle of Cerignola, 1503, was the first battle in which Spanish musketeers played a decisive role.

Mechanical Evolution: From Matchlock to Flintlock

Early guns, the arquebus, used a matchlock mechanism. A slow-burning match, soaked in a saltpeter solution, was held in a metal clamp. Pressing the lever brought the match down into the priming pan, igniting the powder. Advantage: simplicity and cheapness. Drawbacks: the match went out in the rain, was visible at night, and had to be kept constantly lit, a fire hazard near a powderstore. Rate of fire: two to three shots per minute. In the early seventeenth century, the flintlock mechanism was invented. In this system, a piece of flint was fixed to a metal hammer. Pulling the trigger released the hammer forward, and the flint struck a steel plate, producing a spark. This spark ignited the powder in the priming pan. Advantages: no need for a lit match, function in rainy weather, and instant readiness to fire. Rate of fire: three to four shots per minute. The flintlock musket, also called a fusil, was the standard infantry weapon of Europe for nearly two hundred years, 1650 to 1850. England's famous Brown Bess musket, used in the Seven Years' War and the Napoleonic Wars, was a flintlock with a nineteen-millimeter caliber and an effective range of fifty meters. The flintlock marked an important step toward permanent readiness. A soldier no longer needed to carry a smoking match alongside his powder. He could load his weapon in advance and, at the right moment, simply pull the trigger. This always ready condition pushed war toward surprise and speed. There was no longer any need to

light a match and form long ranks. In the Napoleonic Wars, regiments could go from marching to combat readiness and open fire within minutes.

The Tactical Revolution: Line and Column, and Coordinated Fire

With the spread of the gun, tactics of war were transformed. Archers could fire from behind a shield or fortification and could be spread out at scattered intervals. But a musketeer, to fire effectively, needed tight, coordinated ranks. The reason was volley fire. A single gun, on its own, had poor accuracy. But if a hundred guns fired together, a cloud of lead flew toward the enemy that was certain to strike a number of them. To maximize this effect, soldiers stood in ranks of three or four men. The first rank fired, then knelt so the second rank could fire, and so on. By contrast, large infantry columns, used for bayonet charges, were vulnerable. The Battle of Waterloo, 1815, is a classic example: French columns charged the British lines repeatedly, but were halted by successive volleys from flintlock muskets fired from behind a low stone wall. This battle showed that order and fire triumphed over courage and numbers. Modern infantry was the product of exactly these tactics. A soldier was no longer an independent warrior, but a cog in a great machine. He had to stand in rank, obey his commander, and fire at the appointed moment. Individual initiative was not only useless but harmful, since it disrupted the order of the ranks. In this way, a military culture rooted in absolute obedience, iron discipline, and repeated drill took shape. A soldier had to train so thoroughly that loading and firing under the stress of battle became automatic. This kind of training turned a man into a war automaton.

The Bayonet: A Return to Close Violence

The gun had one great weakness: after firing, reloading took fifteen to thirty seconds. During this interval, the soldier was completely defenseless. If enemy cavalry charged, or enemy infantry attacked with swords, the musketeer could do nothing. The solution was the bayonet: a long blade, thirty to fifty centimeters, fixed to the muzzle of the gun, turning it into a kind of short spear. The bayonet was invented in France in the late seventeenth century and quickly spread across Europe. With the bayonet, a musketeer could, immediately after firing, assume a defensive posture and repel an enemy charge. Likewise, in a final assault, regiments could charge the enemy with bayonets fixed. The Battle of Malplaquet, 1709, was the first battle in which the bayonet played a decisive role. The bayonet created an interesting paradox: the gun, built to remove violence from the body, returned to close violence once more through the bayonet. Soldiers in the ranks, after exchanging a few volleys, would engage in hand-to-hand combat with bayonets. Bayonet wounds were deep, dirty, and extremely painful. Even so, the bayonet became a symbol of infantry courage.

The Cartridge and the Simplification of Loading

Loading early guns was a multi-step, time-consuming process. Under the stress of battle, many soldiers forgot a step or poured in too much powder. To simplify this, the paper cartridge was invented in the late sixteenth century. The paper cartridge contained a precise amount of powder and a lead ball, wrapped in paper. The soldier tore the paper with his teeth, poured the powder into the barrel, placed the ball, still wrapped in paper, into the barrel, and rammed it down with a rod. The rate of fire rose to two or three shots per minute. Later, the copper percussion cap reduced this process to a single step, pulling the trigger. In 1849, the breech-loading rifle was invented. This gun opened from the rear, and the soldier placed the cartridge directly into the chamber. There was no need to ram anything down. The rate of fire reached eight to ten shots per minute. Most importantly, a soldier could now lie down or fire from behind cover. The high point was the unified metal cartridge, which spread in the 1860s. This cartridge combined the bullet, the powder, and the primer within a single brass case. After firing, the empty case was ejected by pulling a lever, the bolt, and a new cartridge was loaded in. The famous rifles of that era, the French Chassepot, the German Dreyse, and the American Winchester, all used metal cartridges. The rate of fire reached twelve to twenty shots per minute. A soldier could load and fire while lying prone behind cover, without raising his head. This meant death from behind a shelter, without ever seeing the enemy. Psychological and physical distance had reached the maximum possible for a handheld weapon.

Effects on Society: The National Army and the Citizen-Soldier

The gun transformed the army from a mercenary, professional force into a popular, national institution. In feudal systems, the army was made up of knights, nobles, and mercenaries. Ordinary people had no role in war, except as logistics. But with the gun, any young man could become an effective soldier within a few months of training. This

allowed states to form vast armies from the mass of the people. The French Revolution, 1789, and the Napoleonic Wars, 1803 to 1815, marked the height of this trend. Revolutionary France, through the levée en masse, general conscription, formed an army eight hundred thousand strong. The citizen-soldier was a new idea. Until then, soldiers had often been prisoners, the destitute, or foreign mercenaries with no loyalty to the nation. But the soldiers of the French Revolution, who went to the front with passion and zeal, easily crushed the old mercenary armies. At the Battle of Valmy, 1792, the fresh French army stood against the Prussian army. National armies turned war into a matter for the entire nation. In the Napoleonic era, the whole population, including women, children, and the elderly, was drawn into the war effort: women sewed ammunition pouches and clothing, children carried bread and water, the elderly collected money and equipment. In the Napoleonic Wars, roughly three million soldiers and one million civilians lost their lives. This pattern later reached the height of catastrophe in the First and Second World Wars.

Limitations and the Rise of the Automatic Weapon

Even so, cartridge rifles, even with metal cartridges, had serious limitations: limited effective range, up to three hundred meters for rifled guns, a low rate of fire, a maximum of twenty rounds per minute, and barrel overheating after several volleys. To overcome these limitations, military engineers began thinking about automatic fire. The first attempts to build a machine gun came in the 1860s. The Gatling gun, 1861, with several rotating barrels, fired by turning a crank and had a rate of fire of two hundred rounds per minute. The turning point was the Maxim machine gun, 1884, which used the force of recoil to eject the spent case and chamber a new round. By holding down the trigger, a Maxim gun could fire six hundred rounds per minute. The arrival of the machine gun, as Chapter Fifteen will show, turned war into a static, catastrophic deadlock.

Chapter Summary

Chapter Thirteen has shown that the rifle, from matchlock to bolt-action, shattered the traditional boundaries of war. Individual skill, swordsmanship, archery, was rendered worthless, replaced by order, discipline, and volume of fire. Feudal armies, made up of knights and elite mercenaries, gave way to mass national armies. The bayonet brought personal violence back to the battlefield, but breech-loading rifles and the metal cartridge eventually eliminated direct contact altogether. The rifle transformed war from a martial art into an industrial process. Killing no longer required any particular courage. It was enough for a soldier to be trained, to obey orders, and to stand in his ordered rank. He no longer bore the responsibility of the decision to kill; the commander decided, and he merely pulled the trigger. This distribution of responsibility lowered the psychological threshold of violence to a dangerous degree. The next chapter, Artillery, Mass Fire, and the Industrialization of Destruction, will show how this same logic led to still higher levels of mass killing.

Chapter 14

Artillery, Mass Fire, and the Industrialization of Destruction

The Pivotal Moment: February 21, 1916, Verdun, France

It was 7:15 in the morning. The Germans had positioned 1,200 guns along the twenty-kilometer Verdun front. In a single moment, a million shells were fired at the French positions. The ground shook. Ten-meter concrete bunkers cracked like eggshells. French soldiers hunched in their bunkers felt the sound of the explosions not with their ears but in the bones of their chests. Many eardrums burst. Their faces turned black with dust and smoke. A French soldier named Louis Barthas wrote in his diary that the ground shook like a piece of paper in the hand of a mad giant, that there was no longer any sound, only tremor, that his comrade Marcel stood beside him shouting, but he heard nothing at all, and that suddenly Marcel's eyes bulged from their sockets and he fell to the ground, struck by a direct hit to the bunker, with no scream, no cry, not even a trace of blood, only a crater, and a single hand hanging over the edge of the trench. The Battle of Verdun lasted ten months. Seven hundred thousand men were killed or wounded. The front line shifted only a few kilometers. Artillery, alone, accounted for seventy percent of the casualties. This was no longer war. It was a factory of death.

Eyewitness testimony, from the margins of the Battle of Verdun, 1916, rendered here in translation, describes approaching the front line, a ten-meter crater every hundred meters, crows and rats everywhere, a rat leaping out from beneath the clothes of a dead soldier who had no torso left; the commander said not to look back, but the writer could not look away; the ground was littered with hands, feet, and fragments of bone, and the living slept among the dead. From the memoirs of the German soldier Erich Maria Remarque, who later wrote the novel *All Quiet on the Western Front*.

From the Stone Cannon to Strategic Bombing

If the gun democratized violence, artillery industrialized it. With the cannon, states could destroy an enemy from a distance of several kilometers, without a single soldier ever approaching the battlefield. Artillery was born in the fifteenth century with the bombardment of the walls of Constantinople. In the Napoleonic Wars, artillery became the god of war. Napoleon Bonaparte, himself an artillery officer, said that God fights with the big battalions, but that victory belongs to the best artillery. Nineteenth-century artillery saw three major innovations. First, steel cannon replacing bronze, lighter and more durable. Second, explosive shells replacing stone balls, which detonated on impact and produced shrapnel. Third, an advanced aiming system that reduced error from fifty meters at a thousand meters to twenty meters. With these innovations, artillery could target point targets, such as a bridge, a munitions depot, or a headquarters, rather than only massed formations. But the peak of artillery's industrialization came with the American Civil War, 1861 to 1865, and the Franco-Prussian War, 1870 to 1871. In the Civil War, casualties from artillery fire surpassed those from rifle fire, roughly sixty percent against forty percent.

Types of Modern Artillery

On the eve of the First World War, artillery was divided into three main categories.

Field artillery: light and mobile, with a caliber of seventy-five to 105 millimeters. The most famous example was the French seventy-five-millimeter gun, the Canon de 75, introduced in 1897. This gun had a hydraulic recoil system that returned the barrel to its position after each shot. Its rate of fire was fifteen rounds per minute and its range eight kilometers. This gun was so superior at the outset of the First World War that the French called it the mother of modern artillery and used it to halt the German advance at the Battle of the Marne, 1914. Its weakness was that its seventy-five-millimeter shell was far too weak to destroy the concrete German bunkers built in 1915 and 1916.

Heavy artillery: with a caliber of one hundred to 210 millimeters and a range of ten to fifteen kilometers. The most famous example was the German 150-millimeter sFH 13. These guns could hurl shells of forty to fifty kilograms and could destroy concrete bunkers. At Verdun, the Germans used precisely these guns.

Super-heavy siege artillery: with a caliber of 210 to 420 millimeters and a range of up to fifteen kilometers. The most famous example was Germany's Big Bertha, with a caliber of 420 millimeters, built in 1914. Its shell weighed 820 kilograms and its range was twelve kilometers. This colossal gun, forty-three tons, was built to destroy the Belgian fortifications at Namur and Liège. Another gun, called the Paris Gun, with a caliber of 380 millimeters, bombarded Paris in 1918 from a distance of 120 kilometers. This gun, mounted on a rail carriage, with its own thirty-four-meter barrel, launched 106-kilogram shells to a height of forty kilometers, into the stratosphere, and, after three minutes of flight, landed on Paris. This was the first time in history that a capital city was bombarded from such an extraordinary distance, more than a hundred kilometers.

Indirect Fire and the Birth of Ballistic Calculation

One of the most important artillery innovations of the early twentieth century was indirect fire. Before this, artillery had to see its target directly, meaning the gun stood in a direct line of sight to the target. With indirect fire, artillery could hide behind hills and fire using a forward observer, who saw the target and radioed its coordinates. This system separated the front line from the artillery and increased the safety of gunners. For ballistic calculations, barrel angle, powder charge, flight time, wind effect, and air temperature, ballistic tables, manual calculations based on the equations of projectile motion, and theodolite instruments, for precisely surveying the enemy's position, were employed. By the end of the First World War, artillery had become an immense, complex machine requiring specialized units: spotters, radio operators, ammunition logistics, and maintenance.

In the Second World War, counter-battery radar was developed, which could track the trajectory of an incoming shell and calculate the position of the enemy gun, directing counter-fire against it. From 1942 onward, this technology gave the Allies a considerable artillery advantage over Germany.

Eyewitness testimony, from the margins of the Eastern Front, 1943, rendered here in translation, recalls being hidden on a hill behind the front line, an observer on a forward hill radioing the coordinates of a German tank column, firing their 150-millimeter gun, feeling the ground fold beneath them, and, a few seconds later, seeing black smoke rise from behind the hill as the observer reported a direct hit, two tanks destroyed; the writer says he never saw the tanks himself, only read the coordinates and pulled the trigger. From the memoirs of the Soviet gunner Ivan Petrov.

Effect on the Battlefield: Attrition and Deadlock

In the First World War, artillery was the principal cause of casualties and the principal reason for the deadlock of the fronts. The Battle of Verdun became the symbol of attritional war, in which the artillery of both sides, firing millions of shells, sought to destroy one another, yet no tactical progress was ever achieved. On the Western Front, artillery was the sovereign of the battlefield. Every advance was accompanied by a creeping barrage: shells fell along an imaginary line fifty meters ahead of the soldiers and then gradually moved forward. Soldiers had to advance directly behind this wall of fire so as to reach the enemy's trenches before enemy soldiers could emerge from shelter. This tactic was dangerous, the risk of friendly fire was very high, an estimated fifteen to twenty percent of British infantry casualties at the Battle of the Somme resulted from their own artillery fire, and it required precise coordination between infantry and artillery that, in practice, was rarely achieved. Soldiers, often slowed by cratered ground, entangled in barbed wire, or simply too slow, fell behind the wall of fire and were then slaughtered by German machine guns. The Battle of the Somme, 1916, and Passchendaele, 1917, were stark examples of the failure of the creeping barrage tactic.

The Social and Psychological Consequences of Bombardment

Artillery bombardment created an experience beyond that of the battlefield itself. Civilians in cities behind the lines, too, came under long-range fire. The bombardment of Paris by the Paris Gun in 1918, though its death toll was relatively small, roughly 250 killed, produced widespread psychological terror. For soldiers on the front line, artillery bombardment was hell. A soldier in a trench might endure days and weeks of continuous, unrelenting explosive noise. Many soldiers experienced shell shock: uncontrollable trembling, resulting from damage to the nervous system, an inability to speak, psychological muteness, amnesia, and nightmares. During the First World War, roughly eighty thousand British soldiers were removed from service due to shell shock. In France and Germany the figures are less complete, but the total number of soldiers afflicted with shell shock in the First World War is estimated to exceed two

hundred thousand. This phenomenon, for the first time in history, demonstrated the dependence of mental health on battlefield conditions and laid the groundwork for the diagnosis of post-traumatic stress disorder in modern psychiatry.

Self-Propelled Artillery and the Doctrine of Mobile Fire

Between the two world wars, 1918 to 1939, military engineers worked on self-propelled artillery, a gun mounted on a tank or truck chassis. This offered two major advantages: artillery could reposition quickly and advance in step with tanks, and crews were protected against enemy fire by light armor. In the Second World War, the Germans built the Wespe self-propelled gun, a 105-millimeter gun mounted on a Panzer II chassis. The Soviets built the SU-76, with a seventy-six-millimeter gun on a T-60 tank chassis. The United States produced the M7 Priest, with a 105-millimeter gun on a Sherman tank chassis.

Self-propelled artillery made the doctrine of mobile fire possible. There was no longer any need for prolonged, multi-day barrages such as Verdun. Artillery could advance alongside tanks and infantry and, in the moment, destroy newly appearing targets, such as a bunker, an enemy tank, or a command post. The tactic of direct support fire was invented in this period: each infantry battalion had its own artillery battery, six to eight guns, directly attached, with an artillery liaison officer at battalion headquarters directing fire. This method increased the speed of advance and reduced casualties from enemy fire. As a result, armies equipped with self-propelled artillery, Germany, the United States, the Soviet Union, held a tactical advantage in the Second World War.

Rocket Artillery and Area Bombardment

In the closing years of the Second World War, rocket artillery emerged. Unlike a cannon shell, rockets have no barrel and propel themselves with their own rocket motor. Advantage: a simple, light launcher, several tubes mounted on a light truck, and a very high rate of fire, several dozen rockets in a few seconds. Drawback: very low accuracy, a circular error probable of one hundred to three hundred meters, owing to the absence of a barrel for initial guidance.

The most famous rocket artillery of the Second World War was the Soviet Katyusha, mounted on a Studebaker truck, which fired sixteen 132-millimeter rockets, each weighing forty-two kilograms with a twenty-two-kilogram warhead. The Germans used the Nebelwerfer rocket launcher, with six 150-millimeter tubes, which produced a distinctive howling sound and earned the nickname Screaming Mimi among Allied soldiers. The Katyusha had an immense psychological effect on the Eastern Front. The sound of the rockets igniting, resembling the howl of a thousand wolves, terrified German soldiers. A single salvo from one Katyusha battalion, roughly thirty-six launchers, could fire 576 rockets in under ten seconds and pulverize an area four hundred meters by four hundred meters. After the war, rocket artillery remained in modern armies as mass-fire artillery. Systems such as the Russian Grad, 122 millimeters, forty tubes, a range of twenty kilometers, an error of fifty to a hundred meters, the Smerch and the Uragan, and, from the West, the American M270, 227 millimeters, twelve tubes, a range of seventy kilometers, with satellite navigation accurate to five to ten meters, and the M142 HIMARS, which gained fame in the war in Ukraine, are modern examples of this generation. HIMARS, using GMLRS munitions with GPS guidance, reduced its error to five meters, effectively transforming rocket artillery from an area weapon into a point weapon.

Eyewitness testimony, from the margins of the Eastern Front, 1944, rendered here in translation, recalls a sound like the howl of a thousand wolves falling from the sky, then the ground beginning to shake, at first mistaken for an earthquake, then seeing fifty-meter trees uprooted and thrown into the air, and armored vehicles crushed like tin cans; after twenty minutes, nothing living remained on the plain; the writer says they called the Katyusha Stalin's Organ, and that its sound stayed with him forever. From the memoirs of the German soldier Hans Müller.

Chapter Summary

Chapter Fourteen has shown that artillery brought violence into its industrial phase. With the cannon, close contact was no longer necessary. Artillery could fire millions of shells from several kilometers away, without ever seeing the enemy, and rain destruction upon the ground. Mass fire brought immense casualties and the psychological attrition of soldiers. Artillery also led to the concentration of power in the hands of states, since only wealthy, industrialized states could produce thousands of guns and millions of shells. From the Battle of Verdun to the Katyusha and HIMARS, artillery has remained one of the central pillars of military power. Even so, the rise of jet aircraft and ballistic missiles

in the second half of the twentieth century pushed classical tube artillery somewhat to the margins, though it never became obsolete. Today's artillery, integrated with radar, drones, and guided munitions, has returned to the field once more. In the next chapter, *The Machine Gun, Static Fronts, and the Collapse of the Dream of Advance*, we will see how the combination of artillery and the machine gun made any advance impossible and turned war into a bloody deadlock.

Special Feature

The Evolution of Personal Firearms (Rifle and Pistol), from the Beginning to the Modern Era

The Rifle: From the First Powders to Modular Barrels

The Age of Powder and the Muzzleloader: Early Guns

Early guns refers to weapons loaded from the muzzle, and whose firing systems evolved from the manual, match-based method to the flintlock and finally the percussion cap. This period spans from the tenth century CE to the middle of the nineteenth century. The defining features of these guns were slow loading, poor accuracy, and heavy dependence on weather conditions, yet they laid the mechanical and chemical foundations of modern weapons.

The Fire Lance and the Hand Cannon

The first firearm portable by a single person was the Chinese fire lance of the tenth century CE. Its makers bound a bamboo tube, and later an iron tube, to the head of a spear. The tube was filled with black powder and one or more metal pellets were placed atop it. Igniting the powder through a small hole at the rear of the tube, with a match or a hot coal, sent the projectiles flying out with a tremendous noise. This weapon's effective range was roughly twenty to thirty meters, and it had no accuracy, but the sound of the blast and the smoke had a great psychological effect on the enemy and his horses.

In fourteenth-century Europe, the hand cannon became common. This weapon consisted of a short iron tube attached to a long piece of wood, an early stock. The shooter tucked one end of the wood under his arm and, with his other hand, brought a sulfur-soaked match near the touch-hole. The risk of premature explosion was very high and aiming was practically impossible, but at very close range it could pierce the armor of a heavily mounted knight.

The Matchlock

In the late fifteenth century, a great transformation occurred: the addition of a shoulder stock and a serpentine mechanism that, on pulling the trigger, brought the match down onto the powder pan. This weapon was called the matchlock. Its mechanism worked as follows: a slow-burning match, a hemp cord soaked in potassium nitrate, which burned at a rate of roughly thirty centimeters per hour, was fixed at both ends of an S-shaped lever called the serpentine. Beside the barrel sat a small pan holding fine priming powder, covered by a metal lid to protect it from rain. Pulling the trigger swung the serpentine downward: first the pan's lid slid away, then the match struck the priming powder. The resulting spark set the priming powder alight, and fire reached the main charge through a small hole in the base of the barrel.

The matchlock's limitations were numerous: the match had to remain lit at all times, a fire hazard at night with a telltale smell of sulfur, it went out in rain or heavy moisture, and the shooter had to constantly tend the match while moving. A skilled shooter's rate of fire was at most one or two rounds per minute. Even so, for the first time, infantry could fire in tight ranks, and the matchlock gradually replaced the archer. The Spanish musket, with its long, heavy barrel fired from a forked rest, is the best-known example of this period.

The Flintlock

In the early seventeenth century, the flintlock entered the field and set the match aside forever. In this system, flint and steel replaced the match. A piece of flint was fixed in the hammer, and opposite it sat a steel plate, the frizzen, which covered the powder pan. Pulling the trigger released the hammer forward; the flint struck the frizzen, producing a spark. At the same moment, the frizzen swung forward, exposing the powder pan. The sparks ignited the priming powder, which reached the main charge through a channel.

The advantages over the matchlock were considerable: no more need for a lit match, meaning concealment at night became possible; fairly good resistance to rain, since the frizzen protected the pan; the rate of fire rose to two or three rounds per minute; and, most importantly, the weapon could be carried in a ready-to-fire state, hammer drawn back, without fire risk. In this same period, the bayonet was added to the gun. At first the bayonet was inserted into the barrel itself, which prevented firing; later, the underslung model was invented. With this innovation, every rifleman was also a spearman.

The most famous flintlock was Britain's Brown Bess, used throughout the eighteenth century. With a caliber of nineteen millimeters, a thirty-gram lead ball, and a smoothbore barrel, its effective range was roughly fifty meters. Rifled flintlocks also existed, which, by imparting spin to the ball, extended effective range to two hundred meters, but were harder to load and were mostly used by hunters and marksmen.

The Percussion Lock

Around 1820, a fundamental chemical breakthrough occurred: the discovery of mercury fulminate, an explosive substance sensitive to impact, unlike black powder, which required an open flame. This discovery made possible the percussion cap: a small copper cylinder containing a small amount of mercury fulminate. A pointed nipple was fitted at the rear of the barrel, and the cap was placed over it. The hammer of the weapon, now with a flat striking surface, struck the cap when the trigger was pulled. The cap detonated, and the resulting flame reached the main charge directly through a channel. There was no longer any open pan, powder exposed to moisture, or flint. The copper cap was fully waterproof, the rate of fire rose to four or five rounds per minute, and reliability in poor weather improved dramatically.

It is worth noting that, before the percussion cap, rifled guns were unsuited to ordinary soldiers because of their difficult, time-consuming loading. But with the percussion cap, armies could gradually move toward rifled weapons. The iconic weapon of this period was the Springfield 1861, used extensively in the American Civil War. This percussion rifle, with a rifled barrel, had an effective range of up to four hundred meters, and a skilled soldier could fire three rounds a minute, an extraordinary figure for a muzzleloader.

How Early Muzzleloading Guns Were Loaded

All matchlock, flintlock, and percussion guns were loaded from the muzzle. The standard steps were as follows: the gun was held upright, and a measure of powder from a metal powder flask was poured into the barrel. Then a lead ball, wrapped in paper or cloth, was placed at the muzzle and pressed in slightly by hand. Using a metal ramrod, the ball was driven down to the base of the barrel to seat on the powder. In matchlock and flintlock guns, special priming powder was poured into the pan, the cover was closed, and the match was set or the hammer drawn back. In the percussion gun, the cap was placed on the nipple and the hammer brought to readiness. Any error, damp powder, a fouled channel, a defective cap, meant repeating the entire process, something that, on the battlefield, usually meant the shooter's death.

Why Early Guns Had Poor Range and Accuracy

The main cause was the smoothbore barrel of most of these guns. The lead ball left the barrel without spin and, after a short distance, began to drift off course owing to aerodynamic instability. A rifled barrel imparts spin to the ball, stabilizing it and tripling or quadrupling effective range. But before the percussion cap, loading a rifled gun was extremely difficult. For this reason, armies preferred the smoothbore for its faster loading, even at the cost of accuracy.

The Unified Cartridge Revolution and the Bolt-Action Mechanism

The most important innovation that rendered early guns obsolete was the unified cartridge. In this cartridge, the bullet, the powder, and the primer are all combined within a single metal case, brass or steel. The bullet sits at the tip of the case, the powder inside it, and the primer at the base. A strike from the weapon's hammer to the base detonates the primer and ignites the powder. This cartridge is waterproof, unified, and extremely fast to load. The unified cartridge matured in the 1860s and immediately transformed weapon design.

The Bolt-Action Rifle

The first new rifle built for the unified cartridge was the bolt-action rifle. This rifle is not automatic, but its manual action is far faster than muzzle loading. The bolt-action mechanism works as follows: on the right side, or rear, of the receiver sits a metal handle, the bolt. After firing, the shooter rotates the handle upward, unlocking it, pulls it back, ejecting the spent case and cocking the striker, then pushes it forward, chambering a new cartridge from the magazine, and rotates the handle back down, locking the barrel. A trained shooter with a bolt-action rifle could fire up to fifteen rounds a minute, while the best muzzleloading percussion guns reached only four.

The world's famous bolt-action rifles include the German Mauser 98, the Kar98k, one of the most accurate and powerful rifles in history; the British Lee-Enfield, with a high rate of fire, up to thirty rounds a minute, owing to its smooth bolt action and ten-round capacity; the Russian Mosin-Nagant, economical and rugged; and the American Springfield M1903. These rifles were the primary infantry weapon in both world wars and many other conflicts. Today, bolt-action rifles remain the most popular choice for hunting and sniper rifles, since their inherent accuracy, owing to a fixed barrel and the absence of moving parts during firing, exceeds that of many automatic weapons.

The Semi-Automatic Rifle

The next step was eliminating the manual motion of the bolt. In a semi-automatic rifle, the energy from firing itself is used to drive the bolt back, eject the spent case, and chamber a new round. The shooter need only pull the trigger, and after each shot, the weapon is immediately ready to fire again. Practical rate of fire reaches forty to sixty rounds per minute. The first successful semi-automatic rifle adopted as a standard army weapon was the American M1 Garand, which entered service in 1936. This rifle, of .30-06 caliber, 7.62 millimeters, with an eight-round clip, was known for the distinctive ping sound it made when the clip emptied. In the Second World War, American forces held a significant tactical advantage thanks to the Garand's faster fire compared to German and Japanese bolt-action rifles.

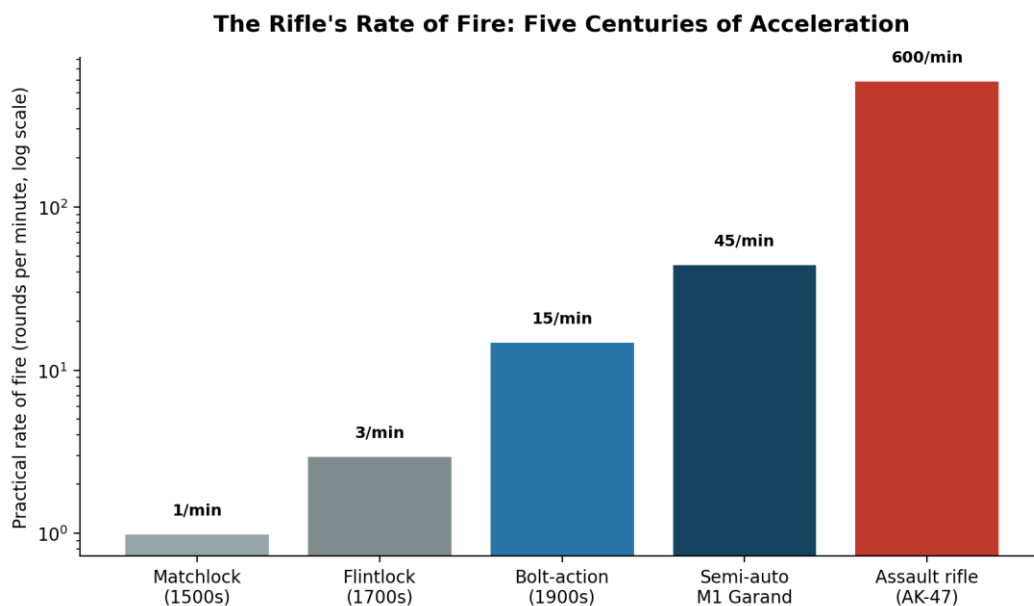


Chart: The rifle's practical rate of fire from the matchlock to the modern assault rifle, log scale (author's diagram, illustrative).

The Soviets produced the semi-automatic SVT-40, designed by Tokarev, but its complexity and sensitivity to dust and dirt led the Red Army instead toward cheaper, fully automatic weapons, the PPSH-41, and later the AK-47. The Germans, too, had the Gewehr 43, but never matched the Garand's mass production.

The Fully Automatic Rifle: The Assault Rifle

In the middle of the Second World War, the Germans introduced a revolutionary concept: the assault rifle. This weapon has three main features: fully automatic fire capability, in which a single trigger pull fires several rounds in

succession; the use of a short, intermediate cartridge, positioned in power between the cartridge of an ordinary rifle and that of a submachine gun; and a compact, lightweight design for ease of carrying. The first practical example was the German StG 44, which entered service in 1944. This rifle used the short 7.92×33-millimeter cartridge and could switch between semi-automatic and fully automatic fire, roughly five hundred rounds per minute. Its effect on the battlefield was such that it astonished the Allies.

After the war, the Russian Mikhail Kalashnikov, drawing inspiration from the StG 44 and combining it with simplicity and reliability, built the AK-47. The AK-47 was designed in 1947 and entered Soviet army service in 1949. This rifle used the 7.62×39-millimeter cartridge, the M43, and, owing to relatively large tolerances between its moving parts, functioned in any condition, mud, sand, snow, water. The AK-47 became the most widely produced rifle in history, over one hundred million units, and a symbol of liberation movements and guerrilla warfare across the world. Its weakness was relatively poor accuracy at long range, beyond three hundred meters, and heavy recoil in fully automatic mode, but its exceptional destructive power and reliability outweighed these shortcomings.

By contrast, the Americans introduced the M16 in the 1960s. The M16 used a smaller, lighter 5.56×45 -millimeter cartridge, which, with a high muzzle velocity and a relatively flat trajectory, offered very good accuracy up to five hundred meters. Its aluminum body and plastic components made it lighter than the AK-47. But the early M16 encountered serious reliability problems in Vietnam, unsuitable powder and the absence of a cleaning rod. After these problems were resolved, it became a highly accurate and popular weapon. The M16 and its derivatives, the M4, remain the standard weapon of American and NATO forces to this day.

Today's War Rifles (from the 1990s Onward)

Today's rifles combine features of both the AK and the M16 with new advances: a Picatinny rail, found on nearly every military rifle's receiver and body, allowing the mounting of scopes, lasers, flashlights, forward grips, and other accessories; composite materials and polymers, bodies made of durable polymers, fiberglass-reinforced nylon, that dramatically reduce weight, as in the FN SCAR or HK416; new and varied calibers, beyond 5.56 and 7.62, intermediate calibers such as 6.8 SPC or 6.5 Creedmoor for greater range and power, with some special units using subsonic cartridges for quieter operations; modular rifles, a single core receiver that can change caliber by swapping barrel, magazine, and bolt, as with the SCAR-L to SCAR-H; sound suppressors and flash hiders, widely used to reduce noise pollution and protect a soldier's hearing; striker-fired weapons, in which many modern rifles, such as the Heckler & Koch G36, use a spring-loaded striker instead of an external hammer; and battery-powered optical sights, red dot or holographic, replacing iron sights on most of today's rifles.

Types by Application

Standard combat rifles: the AK-12, the M4A1, the HK416, the FN SCAR-L, the IWI Tavor, a bullpup design. Sniper rifles: usually bolt-action, the M24, Accuracy International, or semi-automatic, the M110 SASS, in calibers such as 7.62×51 NATO or .338 Lapua, with effective ranges up to 1,500 meters. Anti-materiel rifles: 12.7-millimeter caliber, .50 BMG, for engaging light equipment, vehicles, and helicopters, exemplified by the Barrett M82. Squad automatic weapons: such as the M249 SAW, a light machine gun with a 5.56 cartridge and a heavy barrel for sustained fire. Battle rifles: older semi-automatic rifles with a larger caliber, the M14, the FN FAL, the G3, less commonly used today.

Operating Mechanisms

Gas-operated: the most common method. Some of the hot gas from firing is directed, through a hole in the barrel, to a piston or directly to the bolt carrier. In the M16, gas strikes the bolt carrier directly, giving higher accuracy but greater sensitivity to fouling; the AK has a separate piston, more rugged but heavier. Recoil-operated: the barrel and bolt, locked together, move backward, then unlock, the barrel stops, and the bolt continues rearward. Less common today. Blowback: used in light weapons with low-power cartridges; the bolt has no mechanical lock and is held closed only by spring force.

The Rifles of the Future

In the 2020s, the American army has been transitioning to a new 6.8-millimeter caliber, the NGSW program, with the XM7 rifle firing a high-pressure 6.8×51 cartridge with a composite metal-polymer case. These rifles are equipped with a ballistic computer, a smart scope with laser rangefinding, and a standard suppressor. The goal is penetration of Level IV armor at a range of six hundred meters. Research continues as well on caseless rifles, such as Germany's G11 program of the 1980s, which reduce the weight and bulk of ammunition but have faced problems with heat dissipation and reliability.

In summary, the evolution of the rifle has always rested on three axes: increasing rate of fire, increasing accuracy and range, and increasing reliability in adverse conditions. Early powder guns took the first steps. The unified cartridge and the bolt-action mechanism brought about a revolution in speed. Semi-automatic and later fully automatic weapons with intermediate cartridges brought the concept of individual firepower to its peak. Today a soldier's rifle is a platform of computers and sensors, yet its founding principle, converting the chemical energy of powder into the motion of a projectile, has not changed in seven centuries.

The Pistol: From a Cavalry Weapon to a Polymer Tool

The pistol is a short-barreled firearm designed for one-handed, or two-handed, use at short range, usually up to fifty meters. While rifles evolved for field combat and long-range accuracy, the pistol has always been a weapon of personal defense, an officer's weapon, a cavalry weapon, and a final tool at very close range, under twenty meters. Pistols, like rifles, passed through matchlock, flintlock, and percussion firing systems, but soon split into two distinct paths: the single-shot, the revolver, and the semi-automatic.

Early Pistols: Matchlock, Flintlock, Percussion

The first pistols appeared in sixteenth-century Europe. They were essentially matchlock guns with a shorter barrel and a carved stock for one-handed grip. These early pistols were single-shot: after each firing, powder and ball had to be loaded again from the muzzle, a slow and difficult task in cavalry combat. For this reason, horsemen carried two or three pistols in their saddle, firing one, discarding it, and moving on to the next.

The flintlock pistol reached the height of its popularity in the seventeenth and eighteenth centuries. With a flintlock mechanism similar to the rifle's, this weapon was the primary sidearm of officers and pirates. A famous example is the Queen Anne pistol, with a silver-worked body and a round stock. Calibers were usually between twelve and twenty millimeters, with an effective range of only fifteen to twenty meters. Muzzle loading with a ramrod took up to thirty seconds per shot. Many of these pistols were made with two barrels, over-under, or four barrels, so the shooter could fire several times without reloading.

The percussion pistol replaced the flintlock in the early nineteenth century, increasing reliability, though loading remained from the muzzle. The most famous model was the Naval pistol of the American Civil War. These same percussion pistols laid the groundwork for the revolver revolution.

The Revolver Revolution: Samuel Colt

In 1835, the young Samuel Colt patented the first practical revolver, later named the Colt Paterson. The revolver's idea was a rotating cylinder with several chambers, usually five or six, each holding a complete cartridge, powder, ball, and cap. Cocking the hammer rotated the cylinder, bringing the next chamber in line with the barrel. Pulling the trigger released the hammer, which struck the cap. After firing, the hammer was cocked again, or, in double-action models, pulling the trigger both cocked the hammer and rotated the cylinder.

Colt's revolver mechanism relied on a cylinder lock that prevented premature rotation. This weapon allowed American cavalry to fire six shots in succession while at a gallop. Later revolvers, such as the Colt Walker of 1847, with a .44 caliber and very high power, gained fame in the Mexican-American War. The famous Colt Single Action Army, or Peacemaker, of 1873, with a unified metal cartridge, became a symbol of the Wild West.

Types of Revolver by Action

Single action: the hammer is first drawn back with the thumb, rotating the cylinder and locking the hammer, then the trigger is pulled. The most famous example is the Colt Single Action. Double action: pulling the trigger alone both cocks the hammer, rotating the cylinder, and, at the end of its travel, releases the hammer to fire. Faster to shoot but requiring more finger strength. The hammer can also be cocked manually and then fired with the trigger, for a more precise single-action shot. An example is the Smith & Wesson Model 29, famous as the Dirty Harry gun.

Revolvers, owing to their simplicity and high reliability, if a cartridge failed, pulling the trigger again simply brought the next chamber into line, remained the dominant pistol for more than a century. Their weakness: limited capacity, five or six rounds, and the time required to reload the cylinder.

The Age of the Semi-Automatic Pistol: John Browning

Even as revolvers reached their peak, inventors sought a pistol that could hold more cartridges in a magazine, within the grip, and automatically chamber the next round after each shot. The first successful designs belonged to John Browning. In 1897 he built his first semi-automatic pistol, the FN M1900, in partnership with the Belgian company FN. This pistol used the 7.65×17-millimeter cartridge and a seven-round magazine. Its mechanism was blowback: the bolt had no mechanical lock and was held only by spring force and its own weight. On firing, gas pressure drove the bolt back, ejecting the case, and the recoil spring returned the bolt forward to chamber a new round. This mechanism suited only low-power cartridges. For more powerful cartridges, Browning devised the short-recoil system.

The Colt M1911, designed by Browning and adopted in 1911 as the standard weapon of the American army, is a turning point in pistol history. This .45 ACP pistol, 11.43 millimeters, with a 7+1 round capacity, uses a short-recoil mechanism: after firing, the barrel and bolt, locked together, move backward a few millimeters, then a lever unlocks them, the barrel stops, and the bolt continues rearward to eject the case. The bolt then returns forward, chambering a new round and relocking the barrel. Owing to its high stopping power and excellent accuracy, the M1911 was America's primary sidearm for more than seventy years and remains in use by special units today.

After the Second World War, semi-automatic pistols, drawing inspiration from the M1911 and European models such as the Walther P38, the first double-action pistol with an exposed hammer, and the Beretta 92, gradually pushed revolvers out of military service. The reasons: higher magazine capacity, fifteen to seventeen rounds, faster magazine changes, pressing a button, dropping the empty magazine, and inserting a full one, and a slimmer profile than a revolver's cylinder.

The Polymer Age: Glock and the Modern Generation

In 1982, the Austrian company Glock introduced the Glock 17 pistol, whose frame was made of polymer, a durable plastic, rather than steel or aluminum. This innovation dramatically reduced weight, a loaded G17 weighs roughly 625 grams against 1,100 grams for the M1911. The Glock had no external hammer and used an internal, spring-loaded striker, which was cocked by pulling back the slide. It had three internal safety mechanisms that made accidental discharge without pulling the trigger virtually impossible. Owing to its simplicity, durability, and high capacity, seventeen rounds, this pistol was quickly adopted by police and armies worldwide. Glock has since produced numerous models in calibers of nine millimeters, .40, .45, and ten millimeters.

Today's semi-automatic pistols fall into two main categories: hammer-fired, such as the M1911, the Beretta 92FS, and the SIG Sauer P226, usually with a double-action/single-action trigger, a long, heavy first pull followed by shorter, lighter subsequent shots, with the hammer able to be cocked manually for a lighter first shot as well; and striker-fired, such as the Glock 17, the Smith & Wesson M&P, and the SIG Sauer P320, with no external hammer, a consistent trigger pull on every shot, generally simpler, safer to carry with a round chambered, and less prone to malfunction.

How a Modern Semi-Automatic Pistol Works

Loading: a full magazine is inserted into the grip. The slide is pulled back and released, chambering a round and cocking the striker or hammer. Firing: pulling the trigger releases the striker, or the hammer. It strikes the primer, the primer detonates, the powder ignites, and the resulting gas drives the bullet forward. Ejection and reloading: recoil force drives the barrel and slide, in a short-recoil system, or just the slide, in blowback, rearward. The spent case is ejected. The recoil spring pushes the slide forward again, chambering a new round from the magazine. Slide lock: on

the last round, a lever locks the slide in the rear position. The shooter removes the empty magazine, inserts a full one, and presses the slide release, or pulls the slide back slightly and releases it, chambering the first round.

Comparing the Revolver and Today's Semi-Automatic Pistol

Revolvers today are used mainly for civilian personal defense or in situations where a cartridge might fail, such as mountaineering against bears. Advantages: very high reliability, no need for strong arm strength to rack a slide, and the ability to use extremely powerful cartridges such as the .44 Magnum. Drawbacks: low capacity, time-consuming reloading, and the bulk of the cylinder.

Semi-automatic pistols hold a decisive advantage in military and police use: high capacity, fifteen to twenty rounds, fast magazine changes, one to two seconds, and a slim design. Possible drawbacks: a chance of malfunction if heavily fouled, very rare in good models, and the need for skill in clearing a jam.

Specialized and Future Pistols

Competition pistols: custom 1911s, the CZ Shadow. Subcompact pistols: the SIG P365, with 10+1 rounds of nine millimeter in a very small frame. Hammerless designs: built for pocket carry and snag-free drawing. The future of the pistol points toward smart ammunition, with automatic rangefinding and aim adjustment, fingerprint sensors for safety, and ultra-light materials such as carbon fiber, though the mechanical principles established by Browning and Glock will likely remain in place for decades to come.

Chapter 15

The Machine Gun, Static Fronts, and the Collapse of the Dream of Advance

The Pivotal Moment: July 1, 1916, the Somme River, France

It was 7:30 in the morning. The whistles of British commanders sounded all along the front. Tens of thousands of soldiers leapt from their trenches and, in tight ranks, at a walking pace, advanced toward the German lines, carrying heavy packs and old rifles, and trusting in their commanders' promise that their own artillery had cut the barbed wire and destroyed the enemy's machine guns.

But the artillery had been wrong. The barbed wire still stood. And the German machine guns, in concrete bunkers covered in canvas and earth, waited fully intact. The German soldier Matthias Grünberg watched through the bunker's firing slit as a gray mass of men slowly approached him. His hands trembled on the trigger of the MG 08 machine gun. His commander shouted, fire! Matthias pulled the trigger. The machine gun began to shudder at a rate of five hundred rounds a minute. A 250-round belt emptied in thirty seconds. British soldiers fell to the ground like cut wheat. Matthias loaded the next belt and fired again. By noon he had emptied seven belts. When the firing stopped that evening, no man's land was filled with sixty thousand dead and wounded. Britain suffered sixty thousand casualties in a single day, the bloodiest day in the history of the British army. The front line shifted not a kilometer, but only a few hundred meters. Matthias Grünberg later described that day, saying he did not know whom he was shooting at, that he was only mowing down a mass of shadows like grass, that none of them screamed, they only fell; that for three days after the battle his hands trembled uncontrollably; and that he was no longer that rifleman, but had become a machine, a machine that consumed ammunition and poured out death.

Eyewitness testimony, from the margins of the Battle of the Somme, July 1, 1916, rendered here in translation, recalls leaping from the trench, Bill on the right, Thomas on the left, all of them walking calmly, as though on parade; then the sudden sound of the machine gun, like tearing cloth; twenty seconds later, looking left to where Thomas had stood and finding no one there, only a hand, released into the air, falling; the writer says that was the day he understood that courage was a meaningless word, that the only thing that mattered was luck, the luck of not being hit. From the memoirs of the British soldier George Copeland.

The Birth of the Death Machine

More than any other weapon at the dawn of the industrial age, the machine gun exposed the gap between humanity's image of war and its reality. If artillery and the rifle had smoothed the path toward the industrialization of violence, the machine gun drove that path to a bloody dead end. With the machine gun's arrival on the battlefield, the idea of direct advance, individual courage, and classical maneuver were suddenly rendered obsolete. War, instead of movement, sank into a deadly stillness. Cavalry, which until a century before had been the backbone of armies, stood defenseless before a single machine-gun squad. Infantry, too, could no longer advance in tight ranks toward the enemy.

The machine gun slaughtered any group of humans moving in the open within seconds.

The logic of the machine gun was simple but merciless: converting single shots into a continuous stream of fire. With the Maxim machine gun, 1884, a soldier could, simply by holding down the trigger, fire six hundred rounds a minute. This meant that a single machine gun held the firepower of an entire battalion, five hundred to eight hundred men, of riflemen. There was no longer any question of precise, aimed fire. The machine gun covered a wide area with a wall of lead. Anyone who stepped into that area, whether an enemy soldier, a civilian, a tree, or an animal, was struck. This continuous fire brought the density of death to a level no human body could cross. Before the machine gun, distance, courage, and even numbers lost their former meaning. The battlefield became a space in which visible movement was equivalent to annihilation. Soldiers quickly learned that the only path to survival was to sink into the earth and move only at night or under cover of artillery.

The Maxim Gun and the Early Arms Race

Hiram Maxim, the American inventor resident in England, patented the first true automatic machine gun in 1884. He used the recoil force of the bullet to eject the spent case, draw a new cartridge from a cloth or metal belt, and ready the weapon for the next shot. Maxim offered his weapon to European armies. At first it was met with indifference, but after demonstrations on firing ranges and in colonial wars, it quickly drew attention. In Britain's colonial wars in Africa, such as the Battle of Omdurman, 1893, fifty British soldiers with four Maxim guns massacred roughly two thousand local fighters, who attacked with spear and shield, within a few minutes. The British themselves suffered only four wounded. The Times of London wrote that the enemy's dead were beyond counting, that the machine guns, like a reaping machine, had mowed down their ranks. The German army, too, quickly adopted the Maxim gun, the MG 08 model. Unlike the British, who saw the machine gun as an offensive weapon, for supporting an advance, the Germans deployed it as a defensive weapon in the trenches. This difference in doctrine had a profound effect on the First World War.

Machine Gun Tactics: Lethal Defense

In the First World War, the machine gun became the primary weapon of defense. A four-man squad, commander, gunner, ammunition handler, and water carrier to cool the barrel, with a single machine gun, could turn an area five hundred meters wide and a thousand meters deep into a forbidden zone. The machine gun was positioned in a concrete or timber bunker and fired through narrow slits that were difficult to spot from a distance. Locating and destroying these bunkers was extremely difficult, short of direct cannon fire, which itself was rarely accurate. A common German tactic was positioning machine guns on a reverse slope, behind hills. As Allied soldiers climbed the hill, the machine guns targeted them from the far side. French and British soldiers called these areas mowing fields, since the machine guns, like a lawnmower, cut down their ranks. Some surviving soldiers, in sheer terror, dropped to the ground and feigned death, hoping the gunner would notice and shift fire elsewhere. But experienced gunners knew that many soldiers feigned death, so after a few minutes they would sweep the same area again to make certain of the living. Machine guns also employed crossfire: two or three guns covered an area from different angles, so that escape between them was impossible.

Eyewitness testimony, from the margins of the Western Front, 1917, rendered here in translation, recalls lying in a shell crater for three days, shrapnel in the right leg, unable to walk; every few hours, a German soldier with a machine gun would stand at the crater's edge and look in; the writer feigned death, pressing his face into the mud and holding his breath; the third time the soldier came, it seemed he looked directly into the writer's eyes, that he saw him, but said nothing and simply left, perhaps tired of killing, or perhaps wanting one man to live to tell others what was happening there. From the memoirs of the French soldier Henri Barbusse, author of the novel *Under Fire*.

Static Fronts: Trench, Barbed Wire, and No Man's Land

Static fronts were the direct product of the combined effect of the machine gun, artillery, and barbed wire. Trenches, deep ditches with timber roofing and concrete bunkers, protected soldiers from artillery and machine-gun fire. Barbed wire slowed any advance and exposed attackers to machine-gun fire. Artillery targeted defensive positions and sought to destroy the bunkers. But together, these three elements formed a unified, highly resistant defensive system. The Western Front, from the North Sea to Switzerland, roughly seven hundred kilometers long, was divided into two main trench lines, forward and rear, and communication trenches. The gap between the two opposing front lines was called no man's land, usually one hundred to three hundred meters wide. No man's land was filled with shell craters, barbed wire, rotting corpses, and enormous rats. No one could cross it by day, since the machine guns detected and targeted any movement. At night, limited raids, reconnaissance patrols or attacks on isolated positions, took place, but at high risk. Life in the trenches was hellish. Soldiers lived in mud, among lice and rats, without adequate sanitation, and on poor food. Trench foot, a condition caused by prolonged immersion of the feet in water and mud, disabled thousands of soldiers. Many soldiers suffered shell shock, PTSD, showing symptoms such as trembling, amnesia, nightmares, and an inability to speak. In total, roughly eighty thousand British soldiers, and an unknown number from other armies, were removed from service owing to shell shock.

Efforts to Break the Deadlock: Tanks, Gas, and Bombing

The machine gun had frozen the front in place. But armies sought ways to break this deadlock. Three main solutions emerged: the tank, poison gas, and aerial bombardment.

The tank, examined in detail in Chapter Sixteen, was the first serious attempt to restore mobility to the battlefield. The tank's steel armor resisted rifle and machine-gun fire, and its tracks could cross barbed wire. The tank could crush trenches and open a path for infantry. But early tanks, the British Mark I, 1916, were slow, six kilometers per hour, unreliable, frequently breaking down, and vulnerable to artillery fire. Even so, their psychological effect on German soldiers was immense. German soldiers, who had never seen such a metal monster, often fled and abandoned their machine guns.

Poison gas, chlorine, phosgene, mustard gas, first used by the Germans in April 1915, sought to neutralize machine-gun defense. Mustard gas, Yperite, was especially insidious: odorless and colorless, it remained active on the ground for up to twelve hours after release. Contact with it blistered the skin, blinded the eyes, and filled the lungs with blood. A victim of mustard gas died in agony over weeks. A gas mask could protect the lungs, but the skin remained exposed. Many soldiers, out of fear of gas, pressed their masks so tightly to their faces that vision and breathing became difficult. Even so, gas could never restore mobility to the front, owing to its dependence on wind direction and delayed effect. Casualties from gas, roughly three percent of total casualties, were negligible compared to those from artillery, seventy percent, but fear of gas far exceeded the gas itself.

Eyewitness testimony, from the margins of a mustard gas attack, 1917, rendered here in translation, recalls a yellow cloud drifting from the German trenches toward them, smelling of garlic and mustard, breathing becoming impossible, the eyes burning; one of the young soldiers failed to remove his mask in time, and his face filled with blisters, his eyes went blind, and his voice became a howl; half an hour later they had to leave him and withdraw, and the writer says he did not want to hear that sound again. From the memoirs of the Canadian soldier John McCrae, author of the poem *In Flanders Fields*.

Aerial bombardment, though still in its earliest stages, sought to target the enemy's supply lines and headquarters, but, owing to poor accuracy, could not yet have a decisive effect on the deadlock of the front. In the First World War, bombers usually flew by night and dropped their bombs somewhat at random on cities and rear bases.

The Social and Psychological Effects of the Machine Gun

Beyond the battlefield, the machine gun had a profound effect on society and culture. For the first time, death became so massive and so anonymous that societies could not process it through traditional rites, funerals, mourning, the naming of the dead. This phenomenon, sometimes called collective shock, contributed to the collapse of belief in progress and rationality within European culture. Artistic movements such as Dadaism and Surrealism, which took shape in reaction to the horror of the war, challenged the very meaning of logic and beauty. War literature, too, was

transformed. Erich Maria Remarque's 1929 novel *All Quiet on the Western Front* offered a stark portrait of the meaninglessness of slaughter by machine gun and cannon, describing soldiers deafened by explosions and blinded by mud, no longer knowing why they fought, knowing only that they had to remain in the trench, not for victory, but simply to survive. This outlook stood in complete contrast to earlier war epics, such as Homer's *Iliad*, in which war was heroic and glorious. The machine gun destroyed the glory of war forever. Politically, the machine gun gave states an efficient means of suppressing internal uprisings. In the Russian Revolution, 1917, the Bolsheviks used Maxim guns against counter-revolutionary forces. In Germany, 1919 to 1920, government forces crushed a communist uprising with machine guns. The machine gun was both a weapon of suppression and a weapon of revolution. This duality shows that violence had not passed entirely out of the state's monopoly, but that a state possessing superior technology could rapidly crush any uprising.

The Limitations of the Machine Gun and the Transition to Assault Rifles

Early machine guns, despite their tremendous firepower, had serious limitations. First, weight and mobility. A Maxim gun, with its tripod and water cooling system, weighed roughly sixty-five kilograms. Four soldiers could barely carry it across uneven ground. Second, the need for vast quantities of ammunition. A machine gun could expend thousands of rounds in half an hour of fighting. Carrying this volume of ammunition was impossible for a small squad. Third, barrel heating. After several sustained bursts, the metal barrel grew so hot it could warp. Water-cooled guns, the Maxim and the Vickers, solved this problem to some degree, but required a large water reservoir, roughly five liters, which posed serious problems in desert or winter conditions. For these reasons, the machine gun could never be used directly in an offensive front line. There was always an established defensive front behind which machine guns took shelter. To break through such a front, mobile, self-propelled weapons, the tank, the aircraft, self-propelled artillery, were needed. Even so, the machine gun proved that traditional attack was futile against modern defense. Until this cycle could be broken, war would descend into attrition and slaughter. It was precisely this tactical gap, the need for a weapon with the firepower of a machine gun but the mobility of a rifle, that later led to the emergence of the assault rifle, such as the *Sturmgewehr 44*.

Chapter Summary

Chapter Fifteen has shown that the machine gun was not merely a new weapon, but the destroyer of the old conceptions of war. Advance in tight ranks, valiant cavalry, and individual courage all lost their meaning before a continuous, indifferent stream of lead. Static fronts, where soldiers remained in trenches for months and years without advancing a single kilometer, became the symbol of industrial war. With the machine gun, death became an industrial commodity: cheap, mass-produced, and anonymous. With the collapse of the dream of advance, war entered a phase in which only fundamental innovations, the tank, the aircraft, and later radar and the atomic bomb, could upset the balance.

Special Feature

The Sturmgewehr 44: Birth of the Assault Rifle

The Pivotal Moment: July 1943, the Eastern Front, near Kursk, the Soviet Union

A German vanguard battalion was advancing across open, exposed plains. Soviet soldiers defended themselves from makeshift trenches with long Mosin-Nagant rifles and heavy Degtyaryov machine guns. The fighting was close; the distance to the Soviet trenches was under two hundred meters. The German soldier Hans Weber set down his standard rifle, the *Karabiner 98k*, and took instead, from his battalion commander, an unfamiliar, strange weapon: one with a curved thirty-round magazine, a steel body, and the ability to fire in bursts.

The commander shouted, free fire! Hans pulled the trigger. But unlike previous rifles, which required working the bolt after every shot, this weapon kept firing. A dry, steady rat-a-tat rang from the long barrel. Within three seconds, Hans had fired five rounds toward the Soviet trench. Soviet soldiers, who expected a breath's pause after every shot, were caught off guard. A Russian sergeant later wrote in his memoirs that the sound was different, not like a rifle, not like a machine gun, something between the two, faster than a rifle, slower than a machine gun, but deadlier than both.

This weapon was called the MP 43. A few months later, Hitler named it the Sturmgewehr 44, assault rifle 44. He did not know that this weapon introduced not merely a new rifle, but an entirely new concept in war, one that later became known as the assault rifle.

Eyewitness testimony, from the margins of the Eastern Front, 1943, rendered here in translation, recalls reaching within 150 meters of the Russian trenches; the writer took the new rifle, heavier than the Karabiner 98k, but with a thirty-round magazine; he pulled the trigger, a short burst, three rounds, then another, five rounds; unlike a machine gun, it was easy to control, with little recoil; they cleared the Russian trench, twenty Russian soldiers inside, none given the chance to raise their heads; the writer says that day he understood that precise marksmanship no longer mattered, that what mattered was volume of fire. From the memoirs of the German soldier Hans Weber.

Historical Background: The Machine-Gun Deadlock and the Need for a New Weapon

On the Eastern Front of the Second World War, German infantry confronted a bitter reality: real combat mostly occurred at ranges under three hundred meters. Classic rifles, such as the Karabiner 98k, were too large, slow, and powerful for this range. Their standard 7.92×57-millimeter cartridge, with a muzzle energy of roughly 3,600 joules, carried so much surplus force that, at three hundred meters, much of the bullet's energy was wasted, while producing heavy recoil. Their rate of fire was also low, roughly ten to fifteen rounds a minute. Heavy machine guns, such as the MG 34 and MG 42, on the other hand, had tremendous firepower, up to 1,200 rounds a minute, but their great weight, more than eleven kilograms with a tripod, reduced mobility, and their ammunition was heavy as well.

German infantry needed a weapon that offered a higher rate of fire than a rifle, at least sixty rounds a minute in short bursts, better accuracy than a machine gun at three hundred meters, lighter ammunition, for greater carrying capacity and reduced recoil, and usability by an ordinary soldier. This outlook was itself an intellectual revolution: the weapon was no longer designed for an elite marksman, a sniper, but for the mass infantry soldier fighting on the front line.

The Birth of the Sturmgewehr: From the MP 43 to the StG 44

The project to build an automatic rifle with an intermediate cartridge began in Germany in the late 1930s, but faced delays owing to resistance from the high command, which remained loyal to traditional long, powerful rifles. In 1942, the companies Haenel and Walther presented their prototypes. The MP 43, Maschinenpistole 43, originally classified as a submachine gun, used the new 7.92×33-millimeter Kurz, meaning short, cartridge.

Hitler, who had initially opposed its mass production, worried about the logistical complexity of a new ammunition type, personally chose the name Sturmgewehr 44, assault rifle 44, after seeing the results in the field on the Eastern Front, particularly in the battles near Kursk and the Dnieper, which showed this weapon's decisive superiority over ordinary rifles and even light machine guns. This naming matters because the word Sturmgewehr later entered every army in the world as an independent weapons category, the assault rifle.

Technical Innovation: The Intermediate Cartridge, the Large Magazine, and Selective Fire

The technical innovation of this weapon can be summarized in three areas. First, the intermediate cartridge, the 7.92×33 Kurz, with a muzzle energy of roughly 1,900 joules, against 3,600 joules for the standard rifle cartridge. This reduced energy sharply cut recoil, making automatic-fire control possible even for ordinary soldiers. It also allowed a soldier to carry more ammunition, from sixty rounds of the long cartridge to ninety rounds of the short cartridge at the same weight. The Kurz cartridge was designed in a bottleneck shape to fit more propellant into a smaller volume. Second, the high-capacity thirty-round magazine. Unlike the five- or ten-round single-stack magazines of ordinary rifles, such as the Karabiner 98k, the Sturmgewehr's magazine was double-stack, fifteen rounds per row, thirty total, allowing a soldier more sustained fire without frequent reloading. The magazine's curved shape resulted from accommodating the tapered Kurz cartridges. Third, selective fire: a three-position lever let a soldier choose between safe, semi-automatic, single shots for precise fire at medium range, and fully automatic, bursts for suppression at close range. In fully automatic mode, the rate of fire was roughly five hundred to six hundred rounds a minute.

Operating Mechanism: Gas-Operated with a Tilting Bolt

The Sturmgewehr 44's mechanism is gas-operated with a tilting bolt. Its precise operation is as follows. After firing, some of the hot powder gas trapped in the barrel escapes through a small gas port and is directed, through a narrow gas tube, to a short-stroke piston. This piston, which moves only a few centimeters, strikes the bolt carrier and drives it rearward. During this motion, a guide pin in the carrier forces the bolt to tilt downward and disengage from its locking lug, an action called unlocking. The carrier, together with the bolt, then continues rearward, ejecting the spent case, and the return spring compresses. On the return stroke, the spring drives the carrier and bolt forward, a new cartridge is stripped from the magazine and chambered, and finally the bolt tilts upward again, relocking the action. This tilting-bolt system later inspired the Kalashnikov, though Kalashnikov used a rotating bolt instead, which had larger internal tolerances and proved more reliable in mud, sand, and dirt.

Technical Specifications and Combat Performance

The technical specifications of the StG 44 were as follows: caliber, 7.92×33 millimeter Kurz; empty weight, roughly 4.6 kilograms; length, 940 millimeters; barrel length, 420 millimeters; rate of fire, five hundred to six hundred rounds per minute; muzzle velocity, 685 meters per second; effective range, three hundred meters in fully automatic mode and up to five hundred to six hundred meters in semi-automatic mode with a skilled shooter.

The Sturmgewehr 44 entered the war late, mainly in the second half of 1943 and chiefly in 1944 and 1945. Total production was roughly 426,000 units, a small figure compared to the millions of ordinary rifles, fourteen million Karabiner 98k, and the many millions of later Kalashnikovs, over one hundred million. But every unit equipped with this weapon gained a clear tactical advantage. A nine-man squad equipped with the StG 44 had an effective firepower of roughly five hundred rounds a minute, against two hundred rounds for a squad with ordinary rifles. Ammunition carried by each soldier rose from sixty ordinary rounds to ninety rounds of the Kurz cartridge.

On the Eastern Front, Soviet soldiers spoke of this weapon with dread, calling it the fast German weapon. On the Western Front, American soldiers, too, after encountering units equipped with the StG 44, such as the 352nd Infantry Division in the Battle of the Bulge, 1944, reported that this weapon combined the firepower of a light machine gun with the portability of a carbine. Its main weakness lay not in its design but in Germany's industrial infrastructure. In 1944 and 1945, a shortage of strategic materials, copper for cartridge cases, antimony for hardening lead, and chromium for barrel steel, reduced firing quality and the durability of certain parts. The 7.92 Kurz ammunition also did not align with the Wehrmacht's standard production lines, designed for the long 7.92×57 cartridge, and this logistical problem was never fully resolved.

Legacy and Influence on Later Weapons

The Sturmgewehr 44 can be regarded as the ancestor of all modern assault rifles. The concept of the assault rifle, a weapon with an intermediate cartridge, a large magazine, over twenty rounds, selective fire, semi- and fully automatic, and a design for combat at ranges up to three hundred meters, derives directly from the StG 44.

The most important heir to this thinking is the AK-47. Mikhail Kalashnikov himself acknowledged that he borrowed the idea of combining automatic fire with light ammunition from the StG 44. The main difference lies in the locking mechanism: the StG 44 used a tilting bolt, which required precise, sensitive parts, while the AK-47 used a rotating bolt with two large lugs and a long-stroke gas piston, with large internal tolerances that functioned in mud, sand, and dirt. The result was a weapon that filled the world.

Other postwar assault rifles, such as the Belgian FN FAL, the German HK G3, and the American M16, though differing in cartridge and mechanism, inherited the founding principles, an intermediate cartridge, a large magazine, selective fire, from the StG 44. Even today, the new generation of assault rifles, such as the HK416, the FN SCAR, and the AK-12, still rest on these same founding principles: selective fire, an intermediate cartridge, a high-capacity magazine.

Summary: The Missing Link in the Evolution of Infantry Weapons

The Sturmgewehr 44, despite its limited numbers and late entry into the war, was one of the most influential weapons of the twentieth century. It showed that an assault rifle could replace both the rifle and the light machine gun on the battlefield, dramatically increasing the mobility and firepower of infantry. In the history of weaponry, the StG 44 was

the missing link between the age of the static heavy machine gun and the age of armored-infantry mobility, the tank and the armored personnel carrier. Without this link, and its successors, the AK-47 and other assault rifles, understanding the transformation of tactics in the latter half of the twentieth century, and of guerrilla and counter-insurgency warfare, would remain incomplete.

This weapon, born from the imminent collapse of Nazi Germany, became in practice a model for every army that followed. Today's assault rifle, in every corner of the world, in the hands of NATO soldiers and African insurgents alike, is the direct heir of that German idea, the idea that a front-line soldier needs not a marksman's precision, but a mobile center of fire, an idea that replaced individual courage with collective volume of fire. The Sturmgewehr 44 arrived late, but its arrival changed the way war was thought about forever.

Special Feature

The Kalashnikov Family: A Legacy That Never Dies

The Pivotal Moment: January 28, 1968, Hue, South Vietnam

It was 3:30 in the morning. American soldiers, fully encircled by Viet Cong forces in the city of Hue, held their positions in old houses. The monsoon rain had turned the streets into muddy rivers. The M16 rifles of the American soldiers, fouled with dirty Viet Cong powder residue, jammed one after another, stuck, misfired, spent cases not ejecting. Sergeant John Roberts stared in despair at his rifle. On the ground beside him lay the weapon of a dead Viet Cong fighter: an AK-47. His own weapon useless, he had no other choice. He picked up the rifle, checked the magazine, pulled the trigger. Rat-a-tat-tat. Three rounds in succession. No jam, no hesitation. Mud and grime coated its body, but the weapon worked. Roberts defended the house with that same AK-47 until dawn. After the battle, he wrote in his memoirs that the filthy Russian rifle, in the rain and mud, without a cleaning rod or any maintenance, had worked, while their own M16 failed if a single drop of rain touched it; that he hated America that day, not for its politics, but for the rifle they had given him, and for the rifle he had taken from the enemy.

Eyewitness testimony, from the margins of the Battle of Hue, 1968, rendered here in translation, recalls three days in the trench, rain pouring, mud up to the knee; the writer's M16 failing on the second day, the magazine jammed, the round not ejecting; suddenly Colonel Vincent picking up an AK-47 from a dead Viet Cong soldier and telling the men that this weapon never jams, that from now on anyone who found an AK should set down his M16; the writer says he understood that day that, in war, simplicity and reliability are worth more than complexity and precision. From the memoirs of the American soldier James McCoy.

Background: Mikhail Kalashnikov and the Birth of a Legend

Mikhail Timofeyevich Kalashnikov, a wounded soldier of the Second World War, was wounded in the shoulder during the Battle of Bryansk, 1941, and transported to a hospital. During his convalescence, hearing soldiers complain about the Red Army's unsuitable weapons, particularly the Simonov automatic rifle, the AVS-36, and the Fedorov assault rifle, which were unreliable and failed in the mud and snow of the Eastern Front, he began to consider designing a new weapon. His chief inspiration was Germany's Sturmgewehr 44, examples of which the Red Army had captured on the Eastern Front. Kalashnikov acknowledged that he borrowed the idea of combining automatic fire with light ammunition from the StG 44, but that his goal was to build a weapon an ordinary soldier could trust in any condition, mud, snow, sand, rain.

The final design of the AK-46, the initial version, was presented in 1946, and after revisions, including changing the locking mechanism from a tilting bolt to a rotating bolt, it entered Soviet army service in 1949 as the AK-47, Avtomat Kalashnikova model 1947. Kalashnikov's genius lay in simplicity: the internal tolerances between parts were deliberately made large so that mud, sand, and dirt could not disable the weapon. The use of stamped steel in the body of the AKM version, 1959, dramatically reduced production cost and increased manufacturing speed, from a full day per unit with a milled receiver to a few minutes with a stamped one.

Eyewitness testimony, from the margins of a production plant, 1949, rendered here in translation, recalls working on the AK-47 production line, the parts so simple that even inexperienced workers could assemble them; one day, engineer Kalashnikov visited the factory, picked up a rifle, threw it into the mud in front of everyone, pulled it out, and fired it without any cleaning; the rifle worked; everyone stood stunned; he said this rifle was built for the soldier in the trench, not the engineer in the laboratory. From the memoirs of the Russian worker Ivan Petrov.

The Main Kalashnikov Variants

The Kalashnikov evolved through several main models over the decades.

The AK-47, types one through three, 1949 to 1959: the initial version, with a milled steel receiver, heavy, 4.3 kilograms, and expensive. Caliber 7.62×39 millimeter M43, a curved thirty-round magazine, a rate of fire of six

hundred rounds per minute, an effective range of 350 meters. Only roughly three hundred thousand units of this version were built.

The AKM, Avtomat Kalashnikova Modernizirovanny, 1959, a turning point for the Kalashnikov family. The receiver was made of stamped steel, reducing weight to 3.15 kilograms, 2.9 kilograms without magazine, and cutting production cost to an eighth of the AK-47's. An angled, conical muzzle brake was fitted to the barrel, reducing muzzle climb and improving accuracy in automatic fire. The AKM is the most numerous member of the Kalashnikov family, with more than ten million units built across various countries, including the former Soviet Union, China, the Type 56, Poland, Hungary, Bulgaria, Romania, Egypt, Iraq, and Iran.

The AK-74, 1974: a response to the 5.56-millimeter NATO caliber, whose effectiveness the American M16 had proven in Vietnam. Caliber 5.45×39 millimeter, with a muzzle velocity of nine hundred meters per second, greater than the AKM, and less recoil, owing to the lighter bullet. Weight roughly three kilograms, effective range five hundred meters, an orange or brown plastic magazine, lighter and unbreakable. The AK-74 is the standard rifle of the Russian army and many Eastern Bloc countries, and remains in service today, though gradually being replaced by the AK-12.

The AK-100 series, 1990s: a modern generation, after the collapse of the Soviet Union, with a polymer chassis, fiberglass-reinforced plastic, and a Picatinny rail on the body for mounting optics, scopes, red dots, lasers. The most important models: the AK-101, 5.56 NATO caliber, for export to NATO member countries; the AK-103, 7.62×39 caliber, a successor to the AKM for global markets; and the AK-105, a short carbine version with a 314-millimeter barrel for special forces. This series serves with Russian special forces and many other countries, India, Turkey, Saudi Arabia.

The AK-12, 2012: the newest Kalashnikov generation, with improved ergonomics, a pistol grip, a folding, adjustable stock, an ambidextrous magazine release, a four-sided Picatinny rail, and greater accuracy, owing to a cold, free-floating barrel. It is gradually replacing the AK-74 in the Russian army.

Operating Mechanism (the AKM as a Representative Example)

The AK's mechanism is gas-operated with a long-stroke piston and a rotating bolt. It operates as follows: powder gas escapes through a hole in the barrel and pushes against a long piston fixed to the bolt carrier. This piston and carrier move rearward. During this motion, a guide pin on the carrier forces the bolt to rotate, owing to a helical groove, and unlock. The bolt and carrier then move rearward together, ejecting the spent case, and the return spring compresses. On the return stroke, the spring drives the carrier and bolt forward, a new cartridge is stripped from the magazine and chambered, and finally the bolt locks by rotating ninety degrees, owing to the helical groove on the body and the bolt.

The main difference between this system and the Sturmgewehr 44 is that the StG 44 used a short piston and a tilting bolt, while the AK uses a long piston and a rotating bolt. The long piston delivers more force and functions better in fouled conditions, but produces more vibration and reduces accuracy.

Main Technical Specifications of the AKM

Caliber: 7.62×39 millimeter M43. Empty weight: 3.15 kilograms. Length: 870 millimeters with a wooden stock. Barrel length: 415 millimeters. Rate of fire: six hundred rounds per minute, sixty to one hundred rounds per minute practical in short bursts. Muzzle velocity: 715 meters per second. Effective range: 350 meters, point target, and five hundred meters, area target. Ammunition: 7.62×39 M43, with a steel jacket and lead core, capable of penetrating a steel helmet at up to three hundred meters.

Strengths and Weaknesses

Strengths of the AK: extremely high reliability, owing to large internal tolerances, a robust extractor, and a powerful return spring, the AK fires even after submersion in mud, sand, saltwater, and even after being caked in dirt, without needing to be cleaned; simplicity of design, a small number of parts, roughly ninety, and the ability to be field-stripped and reassembled without tools by a trained soldier in under a minute; low production cost, owing to a stamped body and simply cast and stamped parts; and a high-capacity, easily changed magazine.

Weaknesses of the AK: lower accuracy beyond three hundred meters, owing to the 7.62×39 cartridge's weaker ballistics compared to the 5.56, and the long-piston system, whose heavy moving parts cause the weapon to vibrate; considerable recoil in automatic fire, owing to a relatively powerful cartridge and relatively light weight; poor ergonomics, an old-style wooden grip and stock, and the absence of an optics rail on older models; and a curved magazine that makes carrying it in a pocket or pouch awkward.

Eyewitness Testimony: The War in Afghanistan

From the margins of the war in Afghanistan, 1985, rendered here in translation, an account recalls the Afghan mujahideen using old British and Chinese rifles, but the best among them was the AK-47. A mullah once told the writer that this rifle was made by God, that it did not jam in desert sand, did not freeze in mountain snow, and that a ten-year-old child could strip and reassemble it. He was right. The writer says they repeatedly saw a mujahid fire easily with an AK-47 that had lain in mud and snow for days, without cleaning, without oil; that the Kalashnikov was made for this land. From the memoirs of the Russian journalist Artyom Borisov.

Global Impact and Symbolism

More than one hundred million Kalashnikovs have been built worldwide, counting both licensed and unlicensed production, a figure greater than any other rifle in history, roughly eight million M16s, roughly fourteen million Karabiner 98k rifles, and roughly 0.4 million Sturmgewehrs. The flag of Mozambique and the national emblems of Zimbabwe and Burkina Faso are adorned with the AK-47, a symbol of the liberation struggle. In popular culture, the Kalashnikov has become a symbol of revolution, guerrilla war, and resistance, and, in Western media, of terrorism.

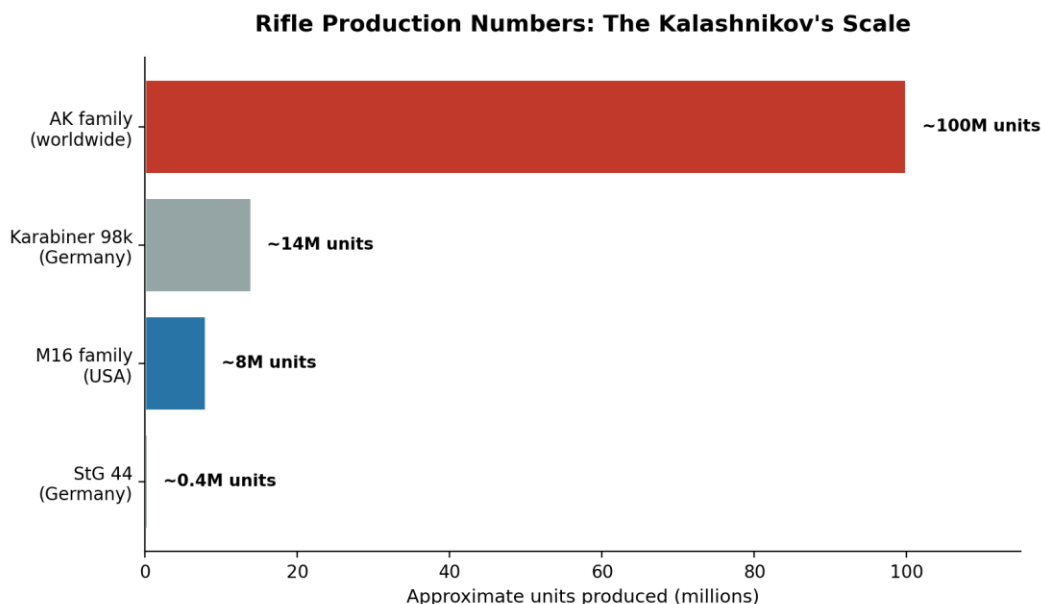


Chart: Approximate total production figures for selected twentieth-century rifles (author's diagram, illustrative estimates). Throughout the Cold War, the AK served as the Soviet Union's primary tool for arming liberation and communist movements in Africa, Angola, Mozambique, Asia, Vietnam, Afghanistan, and Latin America, Nicaragua, El Salvador. In Vietnam, American soldiers, dissatisfied with the early M16, which jammed repeatedly owing to dirty ammunition and the absence of a cleaning rod, sometimes picked up the AK-47s of dead Viet Cong soldiers. This image, an American soldier carrying an AK, became a symbol of America's failure in Vietnam.

Mikhail Kalashnikov died in 2013. In his final testament he wrote that he had suffered his whole life knowing his invention took human lives, but that, given the choice again, he would have done the same, for the defense of his homeland. Today the AK is produced in more than one hundred countries, including Iran, with models such as the KL-7, a copy of the AKM, and other unlicensed versions, and will likely remain in service for several more decades.

Summary: The Final Link in the Democratization of Violence

The Kalashnikov family symbolizes the democratization of violence in its simplest, most unadorned form. At low cost, a few hundred dollars for an AK made in Pakistan or China, anyone, from an insurgent to a professional soldier, can possess a weapon that functions reliably in any weather condition. The AK reduced psychological distance and technical skill to a minimum: unlike earlier rifles, which required a skilled marksman, with the AK, anyone, after a few hours of training, could bring effective automatic fire to bear on the battlefield. In this sense, the Kalashnikov is the ultimate weapon of the masses.

Special Feature

Other Automatic Rifles of the World: Diversity in Design and Mechanism

With the success of the Sturmgewehr 44 and the Kalashnikov, the concept of the assault rifle was adopted worldwide, but each country pursued a different design based on its own military philosophy, geography, and industrial capacity. This survey covers the most important automatic rifles of the second half of the twentieth century, each of which represented an advance in mechanism, ergonomics, or cartridge: the American M16, the Austrian Steyr AUG, the German HK G36, the Belgian FN FNC, and finally the German HK G3, which, owing to its particular importance and role in Iran, receives more extended treatment.

The M16 (United States): The Small-Caliber Revolution and the Direct Gas System

The Pivotal Moment: January 25, 1967, the Ia Drang Valley, South Vietnam

It was early morning. Morning mist rose through the trees of the dense jungle. An American ranger squad, led by Sergeant John Roland, lay in ambush, intending to strike a Viet Cong supply column. Everything was going according to plan. But suddenly a rustling sound came from behind their lines. Roland turned and found himself, at a distance of 1.6 meters, face to face with a Viet Cong soldier aiming a Kalashnikov at his chest. Before Roland could pull his M16's trigger, the Viet Cong soldier fired first. The bullet struck a tree an inch from Roland's face. Roland threw himself backward and raised his rifle. He heard the Viet Cong soldier shout, sixteen, sixteen! Paralyzed with fear, Roland instinctively pulled the trigger. But his M16 had choked. The barrel was full of dirt and moisture, and the round had jammed. Roland prayed and pulled the trigger again. A harsh click sounded from the barrel. The spent case had not ejected. The weapon was dead. After the battle, Roland wrote in his memoirs that in Vietnam, anyone who captured a Kalashnikov from the enemy no longer trusted his own M16.

Eyewitness testimony, from the margins of the Vietnam War, 1967, rendered here in translation, recalls being told that the M16 was the best rifle in the world, fast, light, accurate, flawless; but that on his second deployment to Vietnam he found that his M16 failed in humid, rainy weather, while the enemy's Kalashnikov was as quiet and reliable as a songbird; that he then took a captured AK-47 from the enemy and fought with it for the rest of the war. From the memoirs of the American soldier Bobby Garcia.

Background and Design Philosophy

In the early 1960s, the American army sought a weapon lighter than the M14, which used the 7.62×51 NATO cartridge and proved too heavy and powerful for close combat in Vietnam. Eugene Stoner, an engineer at ArmaLite, designed the AR-15 rifle, which used the new 5.56×45-millimeter cartridge, the .223 Remington. This cartridge, much lighter and smaller than the 7.62 NATO, a bullet weight of 3.6 grams against 9.5 grams, produced far less recoil, and a soldier could carry more ammunition, 210 rounds of 5.56 against 140 rounds of 7.62 at the same weight. After adoption by the U.S. Air Force in 1962 and then the army in 1964, this weapon was renamed the M16.

Operating Mechanism: Direct Impingement

Unlike the AK, which used a long gas piston, the M16 relies on a direct-impingement system. In this system, powder gas escapes through a hole in the barrel and is directed, through a narrow gas tube, straight into the bolt carrier. The compressed gas pushes against a cup built into the carrier, driving it rearward. The bolt, initially locked by a seven-degree rotation, is turned and unlocked by a guide pin. The bolt and carrier then move rearward together, ejecting the spent case and compressing the return spring. On the return stroke, a new round is chambered and the bolt relocks.

The advantage of this system: the absence of a heavy piston, and consequently higher accuracy, owing to the absence of vibration from large moving parts, and lower weight, fewer parts. The major drawback: hot, dirty powder gas, carrying residue from incomplete combustion, is fed directly into the bolt carrier and locking mechanism, fouling the weapon heavily. In Vietnam, American soldiers, owing to a lack of cleaning rods and ammunition with dirty powder, faced repeated M16 jams, a stuck case, the carrier failing to move forward. This problem was resolved by changing the powder to a cleaner type, IMR, adding a chromed chamber, and proper training.

Technical Specifications

Caliber: 5.56×45 millimeter NATO. Weight: 3.4 kilograms without magazine. Length: 1,006 millimeters, A4 model. Barrel: 508 millimeters. Rate of fire: seven hundred to 950 rounds per minute. Effective range: 550 meters, point target. Magazine: a straight thirty-round magazine, owing to the cylindrical cartridge, with a telescoping stock.

Strengths of the M16: high accuracy, owing to the direct-impingement system and a heavy barrel, low recoil, light ammunition, and good ergonomics. Weaknesses: sensitivity to fouling, requiring regular, frequent cleaning, and lower reliability than the AK in mud and sand. The M16 and its improved versions, the M16A2, A4, and the M4 carbine, remain the standard weapon of American forces and many NATO countries.

The Steyr AUG (Austria): The Bullpup Revolution and the Polymer Body

The Pivotal Moment: May 26, 1983, Gibraltar, Southern Spain

A British SAS commando squad, in the dark, stormy dead of night, approached by helicopter the deck of a cargo ship suspected of carrying drugs. Heavy rain fell. Waves crashed against the ship's hull. The squad's commander, Major Jack Russell, carried a new Steyr AUG. This weapon was designed for operations in tight, dark spaces. Its short overall length, 790 millimeters, with a long barrel, 508 millimeters, allowed soldiers to maneuver through the ship's narrow corridors. Russell signaled the squad to move silently. Silence. Suddenly, a shooter fired at them from within the wheelhouse. Several soldiers fell back. Russell pulled the trigger of his Steyr. Within two seconds, he fired five rounds toward the wheelhouse door. The rat-a-tat-tat was steady and controlled. The shooter fell. Russell later wrote in his memoirs that the Steyr AUG was the most accurate rifle he had ever held, that its short length was a dream in tight spaces, but that its magazine, positioned behind the trigger, made a left-handed reload impossible; that as a right-handed shooter it took him an hour to adjust, but after that he never wanted another rifle.

Background and Design Philosophy

In the 1970s, the Austrian army sought a rifle that could simultaneously replace three weapons, the assault rifle, the light machine gun, and the carbine. The Steyr AUG, *Armee-Universal-Gewehr*, universal army rifle, which entered service in 1977, was the first bullpup assault rifle to reach mass production. In a bullpup design, the mechanism, barrel, magazine, and bolt sit behind the trigger, within the stock, so that the overall length of the weapon, with a long barrel, is greatly shortened. The AUG, with a 508-millimeter barrel, is only 790 millimeters long, against 1,006 millimeters for the M16. The AUG's body was made of polymer, reinforced plastic, reducing weight, 3.6 kilograms, and increasing corrosion resistance.

Operating Mechanism: Short-Stroke Gas Piston with Rotating Bolt

The AUG uses a short-stroke gas piston with a rotating bolt. In this system, powder gas drives a short piston, which moves only a few centimeters, rearward. This piston strikes a bolt carrier and drives it back, unlike the Kalashnikov's long piston, where the piston and carrier are one piece. The rotating bolt, with two lugs, unlocks, and the normal cycle

proceeds. The advantage of the short piston: reduced vibration from heavy moving parts, compared to a long piston, and improved accuracy, along with reduced fouling of the locking chamber, unlike direct impingement. The AUG has a quick barrel-change capability, within a few seconds, with a short barrel, for a carbine, or a long one, for a light machine gun role.

Strengths: very short length, excellent maneuverability in tight spaces, urban combat, armored vehicles, a quick barrel-change system, high accuracy, owing to the long barrel and short piston, and a polymer body, light and durable. Weaknesses: no folding stock, the stock is fixed, and the need to adjust to bullpup shooting, the mechanism sits far from the face, the blast is close to the ear, and left-handed reloading is difficult for right-handed shooters. The AUG serves Austria, Australia, the F88 version, New Zealand, Saudi Arabia, and several other countries.

The Heckler & Koch G36 (Germany): Polymer and a Short Piston in One Design

The Pivotal Moment: August 22, 2004, Fallujah, Iraq

It was two in the afternoon. The Iraqi sun was so hot the asphalt was melting. A German infantry squad, part of NATO forces, was patrolling the streets of Fallujah. Suddenly, the sound of a roadside bomb exploded. Brick and ash flew into the air. The German soldier Markus Schmidt, wounded in the arm and face, threw himself behind a destroyed tank. His hands shook violently. He checked his G36 rifle. Its polymer body was coated in dirt and dust, but it still worked. Schmidt took a deep breath and stepped out from behind the tank. To the right, atop a three-story building, he spotted a sniper's hiding spot. Schmidt pulled the trigger of his G36. Three rounds fired in semi-automatic mode. The sniper fell. Schmidt later said the G36 never failed in the heat and dust of Iraq, that its accuracy was less than the M16's, but its reliability was greater, and that he chose the G36.

Background and Design Philosophy

After German reunification, 1990, the German army sought a replacement for the older HK G3, with its 7.62 NATO cartridge and roller-delayed system. Heckler & Koch introduced the G36 in 1995. The G36 used a polymer body, in a distinctive black color, and a short-stroke piston system, but, unlike the AUG, had a conventional, non-bullpup design. The G36 drew attention for combining reliability, like the AK, with accuracy, like the M16.

Operating Mechanism: Short-Stroke Gas Piston with Rotating Bolt

Similar to the AUG. Powder gas drives the short piston rearward, the piston strikes the carrier, the carrier and bolt move rearward, the rotating bolt, with seven lugs, unlocks, the case ejects, the return spring drives the carrier forward, and the action relocks. The G36's gas system has manual adjustment for use in fouled conditions or with a dirty weapon. The G36 is also equipped with a 1.5x scope on the carrying handle in the base model.

Strengths: high reliability, owing to the short piston, good accuracy, a cold, hammer-forged, free-floating barrel, excellent ergonomics, a folding, adjustable stock, a pistol grip, ambidextrous controls, and light weight, 3.6 kilograms. Weaknesses: the polymer body may soften under high heat, after sustained fire, reducing accuracy, a problem reported in Afghanistan and addressed by Germany with the G36V, reinforced, version. The G36 is used by Germany, Spain, the G36E version, Lithuania, the G36KV version, and several other countries.

The FN FNC (Belgium): A Combination of AK and M16

In the 1970s, the Belgian army sought a replacement for the FN FAL, which used the 7.62 NATO cartridge and was unwieldy in close combat, with a weapon in 5.56 caliber. The company FN Herstal designed the FNC, which resembled the AK in appearance, a stamped steel body, a curved magazine, a long charging handle, but used a short-stroke gas piston, rather than a long one, and a rotating bolt. The FNC reduced many of the AK's weaknesses, high recoil, poor accuracy, but its reliability did not match the AK's.

Mechanism: a short-stroke gas piston with a rotating bolt. The FNC has a three-position gas regulator, normal, fouled, for harsh conditions, and off, for firing rifle grenades. The FNC also offers a three-round burst mode in addition to fully automatic and semi-automatic fire.

Strengths of the FNC: better accuracy than the AK, owing to the short piston, less recoil, good ergonomics, a folding, adjustable stock, and acceptable reliability. Weaknesses: more expensive than the AK, and a relatively high weight, 4.4 kilograms. The FNC serves Belgium, Indonesia, and several other countries, and has also been used as a standard weapon by certain special forces.

The Heckler & Koch G3 (West Germany): Veteran of the Cold War Fronts

The Pivotal Moment: August 22, 2004, simultaneous with the G36 account, Fallujah, Iraq — an Iraqi Soldier's Account

Eyewitness testimony, rendered here in translation, recalls having old G3 rifles left over from Saddam's army; heavy, with sharp recoil, but never jamming; having sat gathering dust in storage for years, yet working the moment the trigger was pulled; the writer describes firing a G3 at an American Humvee, the 7.62 round passing through the vehicle's steel body and exploding inside the cabin, something impossible with an AK; they called the G3 the hand cannon. From the memoirs of an unnamed Iraqi soldier.

Background: From an Unfinished German Idea to a Birth in Spain

The story of the G3 traces back to the final years of the Second World War and a secret German project to build a new generation of cheap, mass-producible weapons. Engineers at the Mauser company were, in those years, developing an assault rifle called the Sturmgewehr 45(M), the StG 45(M), which, owing to resource shortages and the end of the war, never reached mass production. This design, built for low cost and simplicity, used an innovative roller-delayed blowback mechanism that later became one of Heckler & Koch's enduring signatures. With the war's end, the German engineers, including Ludwig Vorgrimmler, one of the project's chief designers, were dispersed by Allied forces. Vorgrimmler emigrated first to France and then to Spain, where he continued developing his idea at the Spanish state company CETME. The result of this work was the CETME rifle, built in 7.62×51-millimeter NATO caliber. In the early 1950s, the West German army, the Bundeswehr, seeking a new service rifle, took an interest in the Spanish CETME. After negotiations, the newly founded German company Heckler & Koch acquired a license to produce this weapon and refined it. A key part of this story is that the Bundeswehr had earlier adopted the Belgian FN FAL, under the name G1, but because Belgium refused to license domestic production, the Germans were forced to find an alternative. Finally, in 1959, the Gewehr 3, G3 for short, was adopted as the Bundeswehr's standard weapon. In this way, an idea left unfinished at the end of the Second World War returned to Germany after a decade of wandering and became one of the most successful war rifles in history.

Operating Mechanism: The Roller-Delayed Revolution

The core and principal innovation of the G3 is its roller-delayed blowback locking mechanism, a system that brought Heckler & Koch decades of renown. This mechanism, inherited from the StG 45(M), implements an extremely simple, clever, yet powerful concept. Rather than a gas tube, as in the Kalashnikov, or a gas piston, as in the M16, this system uses the direct force of the case's rearward push to drive the moving parts, but with the difference that two rollers, along this path, act as a buffer and delay to preserve firing safety.

In this system, the bolt consists of two main parts: a light bolt carrier, which carries the moving components, and a bolt head, at whose tip two rollers are fitted on either side. Before firing, the rollers are locked, by an angled locking piece, into special recesses in the body and the barrel trunnion. On firing, powder gas presses against the metal case and pushes it rearward. But rather than this pressure immediately unlocking the bolt head, the rollers must first be driven from their recesses. To do this, the powder gas forces the components to push the rollers inward, unlocking the action. Only after this stage do the bolt head and carrier continue their rearward motion, ejecting the spent case and compressing the return spring. On the return stroke, the spring drives the assembly forward, strips a new cartridge from the magazine, and relocks the rollers into their recesses. This brief delay process produces a controlled rate of fire, five hundred to six hundred rounds per minute, and, owing to the absence of a separate gas tube, makes the weapon simpler, cleaner, and more reliable. Since hot powder gas does not enter the mechanism directly, less fouling accumulates within it. This feature made the G3 an ideal weapon for dusty, dry environments.

Advantages and Disadvantages of the Roller-Delayed System

The main advantage of this system is very high reliability under harsh environmental conditions and low production cost, owing to engineering simplicity. The system requires no gas tube or delicate, complex parts. As a result, the G3 is extremely rugged and low-maintenance. Another advantage is high accuracy. Owing to the absence of a gas tube, which causes vibration from heavy moving parts in ordinary weapons, the G3's barrel remains very stable during firing, making it an ideal platform for sniper variants such as the PSG1 and MSG90.

Among the drawbacks of this system is sharp, unpleasant recoil in fully automatic fire. The absence of a gas tube means relying on direct recoil for the full firing cycle, which requires a brief interval for the rollers to unlock. This produces a hard, sharp recoil that makes the weapon difficult to control in automatic fire. Also, sustained rapid fire in some older models leads to overheating of components.

Technical Specifications and Design

The G3 is an automatic and semi-automatic battle rifle firing the high-energy, long-range 7.62×51-millimeter NATO cartridge, equivalent to the .308 Winchester. Unlike the weaker 5.56 NATO cartridges of assault rifles such as the M16 and G36, this caliber has very high stopping power and range, and can pass through light obstacles, such as a tree, a mud wall, and the body of lightly armored vehicles, though its recoil is also considerably greater.

Its precise technical specifications are as follows: caliber, 7.62×51 millimeter NATO; mechanism, roller-delayed blowback; empty weight, roughly 4.38 kilograms for the G3A3 model; overall length, 1,025 millimeters; barrel length, 450 millimeters; rate of fire, five hundred to six hundred rounds per minute; muzzle velocity, roughly eight hundred meters per second; magazine, five, ten, twenty, thirty, and forty rounds, or bulkier fifty- and hundred-round magazines; ammunition, with high penetration, an effective range of four hundred to five hundred meters, point target, and a maximum range of a thousand meters. The G3's main body is made of stamped, pressed steel sheet. This manufacturing choice, unlike the milled steel used in the M14 and early FN FAL examples, dramatically reduced production cost and accelerated mass production. The stock and handguard in early models were made of wood, but later versions generally use durable plastic.

The G3 Family: A Range of Versions and Upgrades

The G3 family became one of the most extensive weapons families in the world. The most important versions include: the G3A3, the standard model with a fixed wood or plastic stock and handguard; the G3A4, with a folding metal stock, folding to the right, for armored and airborne forces; the G3SG/1, Scharfschützen Gewehr, a sniper model selected directly from the production line, with an optical sight, bipod, and special stock; the HK PSG1, a semi-automatic, extremely precise sniper rifle of worldwide renown; the HK MSG90, a lighter, cheaper version of the PSG1 for military use; the HK21 and HK11, general-purpose and light machine guns based on the G3, with magazine or belt feed; and the HK33 and MP5, G3-family weapons for smaller cartridges, 5.56 NATO and nine-millimeter Parabellum, the MP5 becoming, as a symbol of counter-terrorism weaponry, more famous than the G3 itself.

Service in Iran: An Army Emblem and the Legacy of Generations

The G3 is known in Iran as the Tofang-e Zhe-3, the G3 rifle, and in the mind of every Iranian is bound up with the army, military service, and the courage of soldiers at war. This weapon, from the late 1960s, first imported and then, from the mid-1970s, produced under Heckler & Koch license at the Military Industries factories, later the Defense Industries Organization, has been the official, standard weapon of the army of the Islamic Republic of Iran for more than five decades and is still counted as the organizational weapon of combat and defense units.

The symbol and emblem of the G3 in contemporary Iranian history trace back to the Iran-Iraq War, 1980 to 1988. In those years, the image of Iranian soldiers and combatants with the G3 became one of the enduring symbols of the Sacred Defense. This weapon, owing to its destructive power and high accuracy, was highly effective in urban combat and in open terrain, and was known to the Iraqis as the hand cannon or the black viper, a nickname reflecting its firepower and its ill omen for them. Even today, in parades, at military bases, and even in Sacred Defense films and television series, the image of the G3 immediately evokes Iran's military strength and the sacrifice of its combatants. Although in recent years efforts have been made to replace it with more modern weapons, such as the Sayyad and

Masaf rifles, similar to an Iranian Kalashnikov, the G3 remains one of the most enduring weapons in Iranian military history.

The Legacy of the G3: A Steel Veteran

The Heckler & Koch G3 is the product of a strange and remarkable evolutionary path: from an idea left unfinished in Nazi Germany, to a rebirth in West Germany, to becoming one of the most widely produced and reliable war rifles in history. Its simple, ingenious roller-delayed system, the low cost of production with a stamped steel body, its excellent accuracy, and its powerful cartridge have made it a legend. The G3, despite its sharp, heavy recoil, has earned a place among professional soldiers, snipers, and in the arsenals of more than sixty countries. In Iran, the G3 has become more than a weapon, a symbol of military identity and the legacy of the Sacred Defense. This weapon shows that sometimes an idea left orphaned can become a weapon more enduring than its creator.

A General Comparison of Gas Systems

The direct-impingement system, the M16: light, accurate, but sensitive to fouling. Requires frequent cleaning. Suited to professional forces with good maintenance facilities.

The long-piston system, the AK: heavier, less accurate, but extraordinarily reliable in any condition. Suited to popular militia and guerrilla forces.

The short-piston system, the AUG, the G36, the FNC, and many modern rifles such as the HK416 and the SCAR: a balance between accuracy and reliability. Today the most widely used system in the new generation of rifles.

The bullpup system, the AUG: short length with a long barrel, excellent for tight spaces, but requiring adjustment to the magazine's position and the blast's proximity to the ear.

The roller-delayed system, the HK G3: no gas tube, simple and reliable, but with sharp, heavy recoil. Seen only in the G3 and its derivatives.

Summary: Diversity in Design, Unity in Purpose

The diversity in automatic rifle design reflects a response to differing tactical needs. The United States chose the accuracy and lightness of the M16, at the cost of reliability in harsh conditions. Austria, and, following it, Australia, chose the short bullpup length for urban combat and tight spaces. Germany found a balance between reliability and accuracy with the G36. Belgium, with the FNC, tried to combine the advantages of the AK and the M16. West Germany, with the G3, relied on absolute simplicity and a powerful cartridge, building a weapon that became a symbol of the Sacred Defense in Iran. All these weapons, despite differences in mechanism and ergonomics, shared a common goal: increasing an individual soldier's firepower while preserving mobility and accuracy at ranges up to three hundred to five hundred meters. These principles, a small cartridge, a large magazine, selective fire, continue in the next generation of rifles, such as the HK416, the FN SCAR, and the new generation of Kalashnikovs, the AK-12.

PART FOUR

The Age of Mobility, Sky, and the Deep

Chapter 16

The Tank: Mobility Returns to the Battlefield

The Pivotal Moment: September 15, 1916, Flers-Courcelette, on the Banks of the Somme, France

It was 5:15 in the morning. Thick fog hung over the Somme plains. German soldiers crouched in their trenches, waiting for the usual infantry assault. The whistle of Allied artillery still rang in their ears. But this time, another sound reached them through the fog, a strange sound, like the roar of some legendary creature: the groan of an engine, the clatter of iron tracks, and a trembling of the earth. A German soldier named Kurt Hasse looked out from his trench. His eyes widened in terror. Out of the fog, gray, colossal monsters advanced toward the trenches. Their steel bodies resembled overturned boats. Words were painted on their hulls. British tanks, the Mark I, were entering the battlefield for the first time in history. Hasse shouted, machine gun, fire! But the bullets struck the tank's steel body and deflected harmlessly in every direction. The tank reached the barbed wire. The wire crushed like threads beneath the steel tracks. The tank passed over the trench. Hasse looked up at it. The giant tracks turned a few centimeters above his head. He thought, this is the end. These monsters will never stop. But the tank passed over the trench and moved on toward the second line. Hasse survived. After the battle, he wrote in his memoirs that he had prayed the tank would not roll over his head, and that when it passed over the trench, he understood that the war had changed, that trenches were no longer safe, that machine guns were no longer a barrier, and that cavalry, infantry, and artillery were all meaningless before these steel monsters.

Eyewitness testimony, from the margins of the Battle of Flers-Courcelette, 1916, rendered here in translation, recalls firing at the tanks, the sound of bullets striking the steel body like rain; the tank advancing calmly toward the trenches; a soldier leaping from the trench with an incendiary bottle and running toward the tank; the tank suddenly turning and running him over, the sound of breaking bones audible beneath the tracks; the tank then heading straight for the second line, crushing trenches one by one; the writer says they called the tank the steel devil that day. From the memoirs of the German soldier Kurt Hasse.

From Deadlock to Mobility: The Need for a New Doctrine

The First World War ended in a bloody deadlock in which firepower, the machine gun and artillery, had triumphed over mobility, infantry and cavalry. Trenches, barbed wire, and continuous machine-gun fire had turned any advance into collective suicide. In these conditions, the need was felt for a weapon that could simultaneously overcome three obstacles: break through barbed wire, with its own weight and tracks; remain safe from machine-gun fire, with steel armor; and crush enemy trenches, with direct cannon fire. The answer to this need was the tank. The name tank was a code word the British chose to deceive the enemy; factory workers believed they were building mobile water tanks for the Mesopotamian front.

The tank, unlike many military innovations, was not born from the gradual evolution of existing weapons, but out of necessity, in response to an acute crisis, the deadlock of the Western Front. Its logic combined three elements: armor for survival, an engine for movement, and a gun for destruction. Technologically, the tank was the product of a convergence of the internal combustion engine, developed in automobiles and tractors, steel plate, from shipbuilding, moving tracks, the caterpillar, taken from agricultural tractors, and compact artillery, short guns with recoil buffers. The first tanks, such as Britain's Mark I in 1916, blended these elements; heavy, slow, unstable machines, yet capable of crossing barbed wire and trenches. The limited performance of these early examples nonetheless foreshadowed the path that, in later decades, would make the tank the backbone of modern armies.

Early Tanks and Evolution Between the Two Wars

The first operational tank, Britain's Mark I, was used in September 1916 at the Battle of the Somme. This twenty-eight-ton tank, with two 57-millimeter guns in the male model and four machine guns in the female model, had an eight-man crew and a maximum speed of six kilometers per hour on flat ground. Its armor, six to twelve millimeters, resisted ordinary rifle and machine-gun fire but was vulnerable to artillery fire, seventy-seven-millimeter shells. It had

numerous technical problems: weak, overheating engines that frequently failed, fragile gearboxes, unbearable interior heat, cabin temperatures up to fifty degrees Celsius, and thick exhaust smoke that choked the crew and blocked their vision. Even so, its psychological effect on German soldiers was immense; men who had never seen such a metal monster, with a roaring engine and a trembling earth, often fled and abandoned their machine guns.

The French, too, introduced the Renault FT-17 tank in 1917, a revolutionary design. This 6.5-ton tank, far lighter than the Mark I, was the first tank with a fully rotating 360-degree turret, and had only two crew members, a driver and a gunner/commander. The rotating turret became the standard for every tank that followed, since it let the gunner track a target without moving the entire tank. The Renault FT-17 was also lighter and more reliable than the Mark I, with a speed of eight kilometers per hour, and could be transported by truck or rail. This tank served in more than twenty countries, including the United States, Japan, and Poland, and was still seen in some armies, such as France and Poland, in the Second World War, 1939 to 1945. The concept of the light tank, for reconnaissance and infantry support, originated with the FT-17.

Between the two world wars, 1918 to 1939, military theorists in Germany, Heinz Guderian, Britain, B.H. Liddell Hart and John Fuller, and the Soviet Union, Mikhail Tukhachevsky, worked seriously on the role of the tank in future wars. Two main schools of thought emerged. The first, mainly French and British, saw the tank as an infantry support weapon: the tank should move slowly alongside infantry and destroy enemy trenches and machine guns, low speed, thick armor. The second, German and Soviet, saw the tank as the main axis of offense: tanks should advance in concentrated groups, independent of infantry, at high speed, thirty to forty kilometers per hour, penetrating deep into enemy territory and paralyzing its supply and command lines, while motorized infantry, in trucks and armored personnel carriers, and self-propelled artillery provided support. The victory of the second school, blitzkrieg, lightning war, was decided on the battlefields of the Second World War.

Tanks of the Second World War: From Blitzkrieg to the T-34

German tanks of the late 1930s, the Panzer I, II, III, IV, were designed for speed, up to forty kilometers per hour, and operational range, two hundred kilometers, rather than armor thickness. Their thin armor, ten to thirty millimeters, was vulnerable to anti-tank guns, thirty-seven to forty-five millimeters, but their high mobility let them bypass enemy strong points and avoid engaging enemy strengths, such as heavy French tanks. By contrast, French tanks, the Char B1, had thick armor, up to sixty millimeters, and a powerful seventy-five-millimeter hull gun, but low speed, twenty kilometers per hour, and limited operational range, 150 kilometers. In the Battle of France, 1940, German tanks, equipped with advanced radios in every tank, bypassed the Maginot Line and pushed through the Ardennes forest, which the French had considered impassable to tanks, crushing the French army in six weeks. This was the victory of the independent, fast-tank doctrine over the infantry-support doctrine.

The famous Soviet T-34, introduced in 1940, combined sloped armor. Sloped armor, at a sixty-degree angle, not only increased effective thickness, forty-five millimeters of armor at a sixty-degree slope is equivalent to ninety millimeters of vertical armor, but also caused shells to deflect, or ricochet, rather than penetrate. The T-34 was also equipped with a powerful 76-millimeter gun, later eighty-five millimeters, and high speed, fifty-three kilometers per hour. The Germans, who encountered the T-34 in 1941, were shocked. No German tank, the Panzer III or IV, could at that time pierce the T-34's sloped armor, at least at the usual range of five hundred meters, while the T-34's seventy-six-millimeter gun easily tore through German tank armor, thirty to fifty millimeters. The only countermeasures were superior tactics, firing from the flank or rear, and the use of eighty-eight-millimeter anti-aircraft guns, the Flak 36, in an anti-tank role, which could destroy a T-34 from a thousand meters. The T-34, later with its eighty-five-millimeter gun, came to be recognized as the best tank of the Second World War.

Eyewitness testimony, from the margins of the Battle of Kursk, 1943, rendered here in translation, recalls being in a T-34; the commander calling out a German tank, ten o'clock, seven hundred meters, a Panther; the gunner aiming and firing; the shell striking the Panther's front armor but failing to penetrate; the Panther turning and firing back; the shell passing through their own front armor and striking the engine; the tank catching fire; the writer and the driver leaping out through the bottom hatch; the commander and gunner not coming out alive; the writer says that day he understood their tanks were no longer superior, that the Germans had built better tanks, but that they had far greater numbers.

From the memoirs of the Soviet soldier Ivan Pavlov.

In response to the T-34, Germany developed the heavy Tiger I and Panther tanks. The Tiger I, with one hundred millimeters of front armor, unsloped but very thick, and an eighty-eight-millimeter KwK 36 gun, derived from the eighty-eight anti-aircraft gun, was powerful in direct engagements, but its fifty-seven-ton weight brought high fuel consumption, five hundred liters per hundred kilometers, and low mobility, a maximum road speed of thirty-eight kilometers per hour, but only fifteen to twenty on soft ground. The Panther, with eighty millimeters of sloped front armor and a long-barreled seventy-five-millimeter KwK 42 gun, which had greater penetrating power than the Tiger's eighty-eight at long range, offered a better balance of power and mobility, at forty-five tons. Even so, mechanical complexity and supply-chain problems limited their mass production, roughly 1,350 Tiger I and six thousand Panther tanks. The Battle of Kursk, July 1943, was the largest tank battle in history, in which Germany, with three thousand tanks, including Tigers, Panthers, and Panzer IVs, faced the Soviet Union, with five thousand tanks, T-34s and KV-1s. Despite fierce fighting, the Germans were defeated in this battle, marking the end of German tank superiority on the Eastern Front.

Detailed Survey: The World's Main Battle Tanks

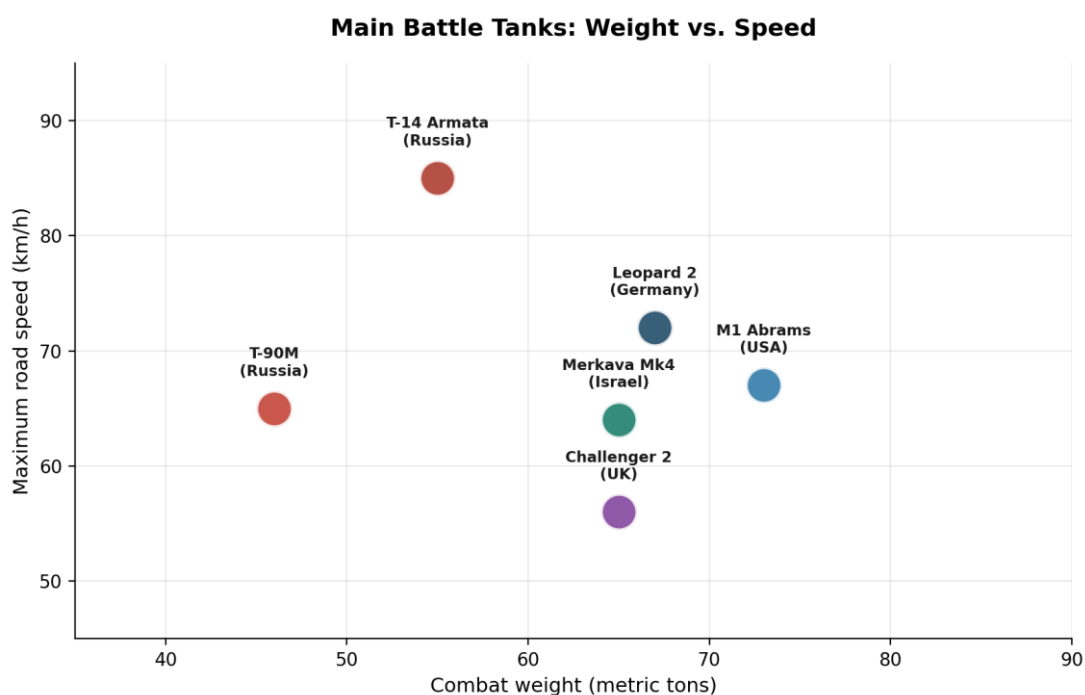


Chart: Combat weight versus maximum road speed for selected modern main battle tanks (author's diagram, illustrative estimates).

Having reviewed the great tank battles, Kursk, the Golan Front, the Valley of Tears, we now turn to a technical introduction and analysis of the most important active tanks in the world today. Each of these tanks reflects the military philosophy, industrial capacity, and strategic threats of its country of origin.

The M1 Abrams (United States): The Heavyweight Workhorse

The M1 Abrams, in service since 1980, is the backbone of American armored forces and of several allied countries, including Egypt, Saudi Arabia, Kuwait, Australia, and Iraq. Named in honor of General Creighton Abrams, commander of American forces in the Vietnam War and later army chief of staff, this tank has evolved through three main generations: the M1, with the 105-millimeter smoothbore M68A1 gun; the M1A1, with the 120-millimeter smoothbore M256 gun, built under license from Germany's Rheinmetall; and the M1A2, with an independent commander's sight, CITV, and a battlefield management system, IVIS. The newest version is the M1A2 SEPv3, System Enhancement Package version 3, in service since 2020, equipped with third-generation depleted-uranium armor on the turret front and hull, with a density two and a half times that of steel, the Trophy active protection system, in some units, for intercepting anti-tank missiles and RPG rockets, and AESA radar for electronic warfare and situational awareness. This tank's combat weight reaches seventy-three tons, including additional armor and the

Trophy system, making it one of the heaviest tanks in the world. Its Honeywell AGT1500 gas turbine engine, with 1,500 horsepower, allows a maximum speed of sixty-seven kilometers per hour and a range of 425 kilometers, though the turbine's fuel consumption is very high, roughly four hundred liters per hundred kilometers. The Abrams's chief strength is its extraordinary front armor, equivalent to nine hundred to 1,100 millimeters of homogeneous steel, and the firepower of its 120-millimeter M256 gun with M829A4 depleted-uranium ammunition, capable of penetrating eight hundred millimeters of steel at two thousand meters. Its weaknesses: very high fuel consumption, gas turbine, heavy weight, complicating air transport, only a few units per aircraft load, and the need for extensive, specialized maintenance, fifty hours of maintenance for every hour of combat operation. The Abrams performed brilliantly in the Gulf War, 1991, and the Iraq War, 2003, with a casualty ratio of one to one hundred against Iraqi tanks, T-55, T-62, T-72; of roughly two thousand Iraqi tanks, fewer than twenty Abrams were completely destroyed.

The Leopard 2 (Germany): Europe's Most Precise Tank

The Leopard 2, in service since 1979, is the gold standard of European tanks, serving in more than ten NATO countries and several other allies, including Turkey, Greece, Finland, Sweden, Spain, Poland, Singapore, and Chile. Known variants include the base 2A4 and the advanced 2A5/2A6, with a wedge-shaped turret for increased front armor and a fifty-five-caliber L55 gun, and the 2A7, with additional armor for urban operations and air conditioning for the crew. The newest version, the Leopard 2A8, ordered in 2024, will be equipped with the Trophy active protection system, a compact AESA radar, and a new 1,600-horsepower engine. The 2A7 model weighs roughly sixty-seven tons and has a maximum speed of seventy-two kilometers per hour. Its MTU-873 diesel engine, with 1,500 horsepower, known as the millennium engine and far more fuel-efficient than the Abrams's turbine, allows a range of 550 kilometers. The Rheinmetall 120-millimeter L55 gun, in the 2A6 and later, has an effective range beyond four kilometers and high penetrating power, the DM63 round, at 1,780 meters per second, penetrates eight hundred millimeters of steel at two thousand meters. Its fire-control system includes a laser rangefinder for the officer, a dual-axis stabilizer, for firing on the move, and a third-generation thermal camera, proven in the Bosnian and Kosovo wars. Composite armor, steel-ceramic-composite, in newer models reaches seven hundred to eight hundred millimeters of steel equivalent at the front. The Leopard 2's weakness compared to the M1 Abrams is relatively weaker side armor, roughly 150 to two hundred millimeters, and the absence of uranium armor. The Leopard 2 suffered losses in Turkey's battles against ISIS in Syria, 2016 to 2018, roughly ten units destroyed, mainly by Kornet missiles and RPG-29 rockets, showing that even top Western tanks are vulnerable without infantry support and electronic warfare against guided missiles.

Eyewitness testimony, from the margins of the Turkey-ISIS conflict, 2017, rendered here in translation, recalls advancing toward the village of al-Bab in northern Syria with a Leopard 2A4; a screeching sound from the left; a Kornet missile, Russian, an advanced anti-tank weapon, striking the tank's side armor from two hundred meters; the Leopard 2's side armor, only about fifty millimeters thick, offering no resistance against the Kornet's 1,200-millimeter penetration; the missile penetrating and detonating inside the tank; the 120-millimeter ammunition inside the turret exploding, the turret separating from the hull and being thrown several meters away; three of the writer's crewmates killed; the writer jumping out through the bottom hatch; the writer says that day he understood a tank without infantry support is just a tin can. From the memoirs of the Turkish soldier Ahmet Yılmaz.

The Challenger 2 (Britain): The Defensive Armored Vehicle

The Challenger 2, in service since 1994, was designed based on lessons from the Gulf War, 1991, and is known as NATO's most heavily armored tank, with full protection against RPG-29 rockets and Kornet missiles. It weighs roughly sixty-five tons, with a maximum speed of fifty-six kilometers per hour, lower than its rivals, mainly owing to its 1,200-horsepower engine, relatively weak for its weight. Its Perkins CV-12 diesel engine, with 1,200 horsepower, gives a range of 450 kilometers. The Challenger 2's chief distinction is its rifled 120-millimeter L30 gun, which, unlike the smoothbore guns of its rivals, the Abrams and the Leopard 2, can fire HESH, High Explosive Squash Head, ammunition. This round, essentially a soft warhead with plastic explosive, does not detonate on impact with the tank's hull but spreads across the surface before detonating. The shock wave transmits through the armor and causes internal spalling on the armor's inner wall, even if the main armor is not penetrated. Chobham armor, the British name for this multi-layered composite armor, combines ceramic, aluminum oxide, heavy steel, Kevlar, to contain fragments, and elastic layers, and reaches an equivalent of eight hundred to nine hundred millimeters of steel at the turret front. No Challenger 2 has ever been destroyed by enemy fire, only one was damaged and burned in Iraq in 2003, from a direct Kornet missile hit to the underside, a weakened part of the armor, though the crew survived. Its weaknesses: low

mobility, especially compared to the Abrams and Leopard 2, a rifled gun, with limited compatibility with standard NATO ammunition, the 120-millimeter smoothbore round, high maintenance cost, and the absence of an autoloader, a human loader who tires during prolonged firing. Britain intends to upgrade 148 Challenger 2 units to the Challenger 3 standard, with a 120-millimeter smoothbore L55 gun, a new turret with a digital fire-control system, new armor, and an autoloader. The Challenger 3 is expected to enter service by 2027.

The T-90 (Russia): A Bridge Between Generations, and the Best Seller

The T-90, in service since 1992, is in effect a deep upgrade of the T-72, using T-80U technology. This tank was designed in response to the T-72's poor performance in the Gulf War, 1991, and the need for a tank with modern reactive armor and a better fire-control system. It weighs roughly forty-six tons, the lightest on this list, with a maximum speed of sixty-five kilometers per hour. Its V-92S2 diesel engine, with one thousand horsepower, gives a range of 550 to 650 kilometers, depending on terrain. Its 125-millimeter 2A46M-5 smoothbore gun has an autoloader, a rate of fire of eight to ten rounds per minute, and can fire the 9M119 Refleks guided anti-tank missile, with a range of five kilometers and penetration of seven hundred to nine hundred millimeters of steel armor. The T-90 is equipped with Kontakt-5 explosive reactive armor, ERA, in the T-90A model, and Relikt, in the T-90M model. Relikt is claimed to be twice as effective as Kontakt-5 and four times as effective as the older Kontakt-1, and effective against tandem, two-stage warhead, missiles. The T-90M, the 2017 version, has a new welded turret, replacing the older cast turret of the T-72/T-90, which had limited interior space, Relikt armor, an 1,130-horsepower engine, and a third-generation thermal camera, the French Catherine-FC, obtained through unofficial channels. The T-90M has approached the protection and firepower level of third-generation Western tanks. Strengths of the T-90: low weight, allowing it to cross weak bridges and be transported by IL-76 aircraft, relatively low cost, two to three million dollars against six to ten million for Western tanks, and mass production, more than 3,500 units by 2024, of which more than two thousand have been exported to India, Algeria, Vietnam, and other countries. Weaknesses: front armor in older models, roughly six hundred to seven hundred millimeters of steel equivalent, is weaker than the Abrams's and Leopard 2's; the autoloader system, positioned beneath the turret within the hull, directly under the crew, increases the risk of ammunition detonation and turret separation if the turret is penetrated, known as the jack-in-the-box effect. Russia, in the war in Ukraine, 2022 to 2024, had by March 2025 lost more than 2,800 T-90 and T-72 tanks; according to Oryx reports, more than 3,600 tanks destroyed, damaged, or captured, of which roughly thirty to forty percent were T-90s. T-90M tanks, too, have shown vulnerability, particularly to FPV drones and Javelin missiles that attack the turret from above.

The T-14 Armata (Russia): A Controversial Fourth Generation

The T-14 Armata, unveiled in 2015, is the world's first operational tank with an unmanned turret, unlike every other tank, where the crew sits in the turret. Its three crew members, driver, commander, gunner, sit in a separate armored capsule at the front of the hull, near the nose, fully isolated from the ammunition. This design dramatically increases crew survivability against direct hits, since ammunition is no longer in the turret above the crew. The T-14 weighs roughly fifty-five tons, with a maximum speed of eighty to ninety kilometers per hour. Its twelve-cylinder A-85-3A, 12N360, diesel engine, with 1,200 to 1,500 horsepower, suffered reliability problems early on, several units stalled on Red Square during the 2015 parade. Its 125-millimeter 2A82-1M gun, without a bore evacuator, the usual gas-venting tube at the barrel's end, has an autoloader in the turret's rear, rather than beneath it, and can fire guided missiles. The T-14 is equipped with AESA phased-array radar on the turret, for tracking aerial and ground targets, and the Afghanit active protection system, claimed to be capable of intercepting APFSDS anti-tank penetrator rounds and modern missiles, though this claim has never been proven on the battlefield. Its new composite armor, steel, ceramic, and composite, includes Malachite reactive armor, a new generation of ERA more effective against tandem warheads. As of 2026, fewer than one hundred T-14 units have been built, estimates suggest thirty to forty operational units with the rest being pre-production examples, and mass production has faced delays, owing to technical complexity, engine and transmission problems, high cost, estimated at four to five million dollars per unit, expensive for Russia, and budget priority given to T-72 and T-90 production for the war in Ukraine. No T-14 has been deployed in the Ukraine war; according to intelligence reports, only a few units have been seen for testing near the border.

The Merkava Mk4 (Israel): A Mobile Fortress for Urban Warfare

The Merkava, meaning chariot, which has evolved since 1979, was designed based on lessons from the Arab-Israeli wars, particularly the Yom Kippur War of 1973, in which Israeli tanks suffered heavy losses owing to insufficient armor. Unlike other tanks, where the engine sits at the rear, the Merkava places the engine at the front, so it functions as additional armor for the crew. The rear space, usually occupied by the engine, is designed to carry infantry, up to six to eight men, or evacuate the wounded, a feature unique in urban warfare. The Merkava Mk4 has a 1,500-horsepower diesel engine, weighs sixty-five tons, and has a maximum speed of sixty-four kilometers per hour. Its 120-millimeter MG253 smoothbore gun, Israeli-made, based on German technology, has an optional autoloader, semi-automatic loading in newer versions. It is equipped with the Trophy active protection system, which has shown high success in intercepting anti-tank missiles in Gaza and Lebanon, claimed to have made more than five hundred successful intercepts by 2020, and advanced thermal cameras. Strengths: crew survival prioritized in the design, the forward engine, rear evacuation space, emergency escape hatches in the hull floor, the proven Trophy system, and troop-carrying capacity. Weaknesses: relatively low speed, sixty-four kilometers per hour against seventy-two for rivals, high fuel consumption, and front armor, estimated at six hundred to seven hundred millimeters of steel equivalent, weaker than the Abrams's, though compensated by Trophy. The Merkava Mk4 was used in Operation Al-Aqsa Flood, 2023, against Hamas in Gaza, and several units were damaged by RPG-7 rockets and Kornet missiles, but the Trophy system intercepted most of them. Casualties were not catastrophic.

The Type 10 (Japan): A Light, Swift Samurai

The Type 10, in service since 2012, was designed for operation on Japan's roads and bridges, which cannot bear weights over fifty tons. Its weight is modularly adjustable: forty tons in transport configuration, with some armor sections removed, and forty-eight tons in full combat configuration, with additional armor fitted. Its low weight and 1,200-horsepower Japanese, Mitsubishi, diesel engine give it an extraordinary power-to-weight ratio, roughly twenty-six horsepower per ton, and a maximum speed of seventy kilometers per hour. It is equipped with a hydropneumatic suspension system that adjusts hull height, for firing at steep angles and moving over rough terrain. Its 120-millimeter smoothbore gun, Japanese-made, Japan Steel Works, has an autoloader, a rate of fire of ten rounds per minute, and an automatic fire-control system with tracking radar, capable of automatically tracking moving targets. Strengths: excellent mobility, the fastest tank in its class, low weight, and an advanced suspension system, improving accuracy while firing on the move. Weaknesses: weaker armor, five hundred to six hundred millimeters of steel equivalent, a deliberate tradeoff for low weight. Limited production, roughly one hundred units by 2022, with plans to increase to two hundred by 2030. Owing to the Chinese threat, Type 99A tanks weighing sixty tons, Japan may design a new generation with heavier armor.

The Type 99A (China): A Leaping Dragon

The Type 99A, an upgrade of the Type 99, reflects China's technological leap over the past two decades. Its design combines Soviet, a 125-millimeter autoloader system, and Western, Abrams-style sloped armor, elements. It weighs roughly fifty-eight tons, with a maximum speed of eighty kilometers per hour. Its 1,500-horsepower engine, a German-Chinese design based on the MTU-883, gives a range of five hundred to six hundred kilometers. Its 125-millimeter smoothbore ZPT-98 gun has an autoloader and can fire anti-tank guided missiles through the barrel, similar to Russia's Refleks but a Chinese version. Its front sloped armor, Western-style, combines steel, ceramic, aluminum oxide, and polymer layers with FY-5 reactive armor, China's fourth-generation ERA. It is equipped with a laser dazzler system, mounted on the turret, that can damage enemy tank targeting sensors. Strengths: a powerful gun, comparable to the 2A46, good mobility, and relatively low cost, three to four million dollars. Weaknesses: armor, estimated, weaker than the Abrams's and Leopard 2's, roughly six hundred to seven hundred millimeters of steel equivalent, a vulnerable autoloader system, similar to the T-90, with ammunition beneath the turret, and metallurgical and electronic quality below Western standards, especially sensors and thermal cameras, some copied from Russia. China has roughly six hundred Type 99A units in service, and more than 1,200 Type 96/Type 99 units. The Type 99A is expected to be replaced by China's fourth-generation tank, possibly the Type 40, by the mid-2030s.

Other Major Tanks of the World

The K2 Black Panther, South Korea: fifty-five tons, a 1,500-horsepower engine, a German MTU-833 licensed by Hyundai, a 120-millimeter L55 gun, licensed from Rheinmetall, a hydropneumatic suspension system capable of tilting for high-angle firing. Strengths: excellent mobility, seventy kilometers per hour, an autoloader, a rate of fire of

twelve rounds per minute. Weaknesses: high cost, 8.5 million dollars, and weak side armor, roughly 150 millimeters of steel.

The Altay, Turkey: based on K2 technology, with assistance from Hyundai Rotem, a 1,500-horsepower engine, MTU, licensed but export-restricted, the AKKOR active protection system, developed domestically and with Israeli assistance. Weaknesses: delayed production, postponed several times, the first batch of 250 units, planned for 2025, was pushed to 2026, and engine problems, owing to Western sanctions on the primary engines.

The Arjun Mk1A, India: sixty-eight tons, the heaviest in this class, a 1,400-horsepower engine, MTU, Germany, a rifled 120-millimeter gun, Indian-made under license. Weaknesses: very high weight, causing transport problems on many bridges and soft ground, logistical problems, delayed spare parts, and frequent maintenance issues, leading the Indian army to turn to T-90 tanks as a replacement.

The T-84 Oplot, Ukraine: an upgrade of the T-80, with a 1,200-horsepower diesel engine, positioned at the rear, unlike the T-80's gas turbine, new Duplet reactive armor, with two layers, and an autoloader. Exported to Thailand, forty-nine units, but production has halted owing to the war.

The Al-Khalid, Pakistan: forty-six tons, based on China's Type 90-II, an upgrade of the T-72, a 1,200-horsepower engine, Ukraine's KMDB, the 6TD-2 engine, and Chinese reactive armor. In service with Pakistan and Morocco, roughly six hundred units in Pakistan. It has performed acceptably against India's Arjun.

The C1 Ariete, Italy: fifty-four tons, a 950-horsepower engine, the weakest power-to-weight ratio in its class, under eighteen horsepower per ton, with an AMV upgrade program planned for a 1,200-horsepower engine. In service with Italy, two hundred units, with a gradual withdrawal from service planned by 2030.

The Leclerc, France: fifty-six tons, a 1,500-horsepower engine, French-made, an autoloader, a rate of fire of ten to twelve rounds per minute, the fastest in its class. Weaknesses: relatively thin armor, roughly four hundred to five hundred millimeters of steel equivalent at the front, compensated by high mobility, seventy-two kilometers per hour, and advanced electronic warfare.

The VT-4, China: fifty-two tons, a 1,300-horsepower engine, a 125-millimeter smoothbore ZPT-98 gun, exported to Thailand, fifty units, Nigeria, and Pakistan, three hundred units. An export version of the Type 99A with certain sensitive technologies removed.

The Weaknesses of the Modern Tank

The high weight of modern tanks, sixty to seventy-three tons, complicates transport; many bridges in Europe and Asia cannot bear weights over fifty tons, and American tanks in Germany, during NATO exercises, must use special bridges. Maintenance costs are high, five hundred thousand dollars a year per Abrams, including spare parts, repairs, and fuel. The tank is vulnerable to modern anti-tank missiles, the Javelin, attacking from above, the Kornet, with high penetration, FPV drones, which can strike weak points such as the rear of the turret, and magnetic mines. The war in Ukraine showed that tanks without air and infantry support, lacking close sensors to detect enemy ambushes, are extremely fragile against armed drones and shoulder-launched missiles. Based on field reports, roughly fifty percent of Russian tanks in Ukraine were destroyed by small drones and handheld rockets, not by enemy tanks.

Eyewitness testimony, from the margins of the war in Ukraine, 2022, rendered here in translation, recalls having a T-90M, the newest version; one day, an enemy drone, a commercial DJI Mavic quadcopter, finding them and revealing their position; the crew dismounting and hiding in a nearby ditch; three minutes later, a Javelin missile striking the turret from above; the tank catching fire; the 125-millimeter ammunition inside the turret exploding, the turret separating from the hull and being thrown roughly twenty meters into the air before crashing into the ground; the writer says he will never forget that scene, a fifty-ton tank thrown into the air like a toy; that after that, they no longer trusted the tank; that a tank without air support and without our own drones scanning the sky is just a large target.

From the memoirs of the Russian soldier Alexei Kuznetsov, recorded by Human Rights Watch, 2023.

Chapter Summary: A King Shedding Its Skin

The tank was humanity's answer to the deadlock of the machine gun. With its steel armor it stood firm against bullets, and with its powerful engine it restored mobility to the battlefield. From the Battle of Kursk, 1943, to the war in Ukraine, 2022 to 2024, tanks have always been both a superior weapon and a vulnerable target. Today, to preserve the tank's effectiveness on the future battlefield, it must be equipped with cooperating drones, giving 360-degree awareness around the tank, active protection systems, such as Trophy and Afghanit, and a new generation of reactive armor. Even so, as long as the need to seize ground by direct force persists, that is, as long as war involves physical occupation, the tank will remain the king of the battlefield, though wearing a crown that grows heavier and more expensive by the day. The new generation of tanks, such as the T-14 Armata and Western concepts, is moving toward unmanned turrets, nanocomposite armor, and full integration into networks of information warfare, a tank that is itself part of a larger system, rather than an isolated metal fortress.

Chapter 17

Maneuver, Coordination, and the Birth of Modern Doctrines of War

The Pivotal Moment: May 1940, the Ardennes Forest, Belgium and France

It was 4:30 in the morning. Thick fog hung over the dense pine and oak trees of the Ardennes forest. General Heinz Guderian, commander of Germany's armored forces, looked out through the observation slit of his command tank. Before him, endless columns of Panzer tanks, armored personnel carriers, and trucks carrying soldiers stood arrayed among the trees. French commanders had declared this region impassable to tanks and had concentrated their defenses on the Maginot Line, the fortified eastern strip. But Guderian knew that Germany's armored columns could cross this forest.

He ordered the radio operator, message to all units: begin the attack. Suddenly, the roar of hundreds of diesel engines tore through the calm of dawn. Tanks emerged from among the trees and streamed toward the dirt roads. At the same moment, in the sky, Stuka dive bombers, with their special sirens producing a howling sound, dove over French positions and dropped 250-kilogram bombs onto the trenches.

The French, who had not expected an attack from this direction, were shattered. Their commanders communicated with one another through motorcycle messengers, who got stuck in the mud, and carrier pigeons, which were sometimes shot down, while every German tank was equipped with a powerful radio, the FuG 5 and FuG 2, and could receive orders instantly and change course. Instead of engaging the enemy's fortified positions, Guderian's tanks passed through the gaps between French divisions and penetrated deep into the French rear. In under forty-eight hours, they reached the English Channel and split the French army in two. Six weeks later, France surrendered. Blitzkrieg, lightning war, proved to the world that speed and coordination had replaced sheer firepower and concrete bunkers.

Eyewitness testimony, from the margins of the Battle of France, 1940, in the voice of a French soldier, rendered here in translation, recalls being positioned in the bunkers of the Maginot Line, awaiting an attack from the east; suddenly, news arriving that German tanks had crossed the Ardennes forest and were now behind them; not believing it; the battalion commander trying to reach headquarters, but the phone line dead; sending a messenger by motorcycle, who never returned, likely killed in crossfire; meanwhile, hearing the howl of the Stukas from the sky, bombs falling on them; after three days, when ammunition ran out and no food remained, since supply lines had been cut from the rear, surrendering; the writer says they fought not against soldiers, but against a system, a system in which they had no radio, but the enemy did. From the memoirs of the French soldier Marcel Lefort.

From Deadlock to Mobility: The Necessity of a New Doctrine

The First World War ended in a bloody deadlock in which firepower, the machine gun and artillery, had triumphed over mobility, infantry and cavalry. Trenches, barbed wire, and continuous machine-gun fire had turned any advance into collective suicide. In these conditions, armies learned that any advance without direct fire support, artillery, and armored protection, the tank, was collective suicide. Yet the war's end was not the end of military thought. Between the two world wars, 1918 to 1939, military theorists in Germany, Britain, France, and the Soviet Union sought a way

to break the deadlock and restore the superiority of mobility to the battlefield. The result of these efforts was the birth of new doctrines such as blitzkrieg, lightning war, in Germany, and Deep Battle in the Soviet Union.

These doctrines emphasized one core principle: speed, concentration, and coordination. Rather than a linear attack along the entire front, which in the First World War led to attrition and entrapment in trenches, forces would concentrate at a specific point, penetration, break through enemy lines using tanks, aircraft, and motorized forces, breach, and then push deep into the enemy's rear, pursuit. The goal was not to destroy the enemy's soldiers one by one, impossible in a war of attrition, but to paralyze the enemy's command, communication, and supply system. An enemy with no commander, headquarters destroyed, no ammunition, depots bombed and supply lines cut, no communication, phone and radio lines cut or intercepted, and encircled, tanks and motorized forces closing off his rear, was, even if he still had armed soldiers, effectively defeated.

Radio and Communications: The Staff of Command

The 1930s saw the miniaturization and stabilization of military radios. While the early radios of the First World War were large and heavy, up to fifty kilograms, and used only at headquarters, advances in vacuum-tube technology and early transistors shrank radios to the size of a small lunchbox. German tanks, from the Panzer I to the IV, were equipped with radio transceivers, the FuG 5 and FuG 2, allowing a tank commander to communicate with other tanks in his platoon and company, and with headquarters, brigade and division. This radio network, in which every tank was a node, made possible the real-time coordination of attacks, rerouting in response to enemy resistance, and tactical flexibility.

By contrast, the French army in 1940, and even the Soviet Red Army in 1941, still used carrier pigeons, in some rear units, and motorcycle, and bicycle, messengers to transmit orders. French tanks, such as the Char B1, had no radio; the commander had to signal his tanks with a flag. On a battlefield filled with smoke and dust, the flag could not be seen and the horn could not be heard. The delay in transmitting orders in the French army was usually thirty to sixty minutes, while the Germans could react within two or three minutes. This difference of a few hours, in responding to enemy movements, was the difference between life and death.

The German theorist Heinz Guderian, regarded as the father of blitzkrieg, insisted that a tank without radio is blind and deaf on the battlefield. He ordered that every German tank, even light command tanks, be equipped with radio. Also, to coordinate aircraft and tanks, air liaison officers, known as Flivo, Fliegerverbindungsoffizier, were present in command tanks, maintaining radio contact with close-support aircraft, the Stukas. Early radios, such as the Funksprecher a, had limited range, roughly two to five kilometers over rough terrain, but with improved antennas, a long whip antenna, 1.5 to two meters, mounted on the tank, and transmitter power, ten watts, range reached fifteen to twenty kilometers by the end of the war. This combined-arms integration of different branches of the armed forces, the army, tanks and infantry, the air force, dive bombers and fighters, and later the navy, became the foundation of the new doctrine.

In the Soviet Union, the Deep Battle doctrine, developed by Mikhail Tukhachevsky in the early 1930s, also emphasized the importance of rapid communications, radio and telegraph. Tukhachevsky was one of the most prominent military theorists of the twentieth century. But Stalin's purges of 1937 and 1938 executed many military theorists, including Tukhachevsky and eighty percent of the Red Army's generals. As a result, the Red Army in 1941 was weak in communications, a lack of radios in many tank and artillery units, and coordination, an excessive focus on strict obedience to central command. Only after the initial defeats, the massive encirclements of 1941, including near Kyiv and Vyazma, where hundreds of thousands of Soviet soldiers were captured, did the Soviets rapidly improve their communication system.

Eyewitness testimony, from the margins of the Eastern Front, 1943, in the voice of a Soviet officer, rendered here in translation, recalls that in 1941, their T-34 tanks had no radio; the battalion commander had to signal tanks with a flag; in dust and smoke, no one could see the flag; as a result, attacks were disorganized and the Germans easily encircled them; in 1943, every T-34 was equipped with radio; suddenly they could act as a single fist; the battalion commander could give direct orders to each tank, tank three, turn right, tank seven, attack from the left flank, tank nine, fire from position; the difference was like night and day; radio became their staff of command; they also realized the Germans always listened to their radio stations, so they introduced simple codes and frequent frequency changes. From the memoirs of the Soviet soldier Dmitri Loza, author of the book *Commanding the Red Army's T-34 Tank Battalions*.

The Air Force: An Umbrella of Support and Deep Bombing

Alongside the tank, military aircraft also evolved. In the First World War, aircraft mainly played a reconnaissance role, observation, and occasionally rudimentary bombing. But in the 1930s, dive bombers such as Germany's Stuka, from *Sturzkampfflugzeug*, meaning dive-attack aircraft, were built. These aircraft were equipped with automatic systems for precise diving. The Stuka pilot dove toward the target at an angle of sixty to ninety degrees and released the bomb at an altitude of four hundred to eight hundred meters. The sound of the sirens mounted on the Stuka, which Joseph Goebbels, the propaganda minister, called the trumpet of fear, struck terror into enemy soldiers.

In the blitzkrieg doctrine, aircraft played the role of flying artillery. Before a tank assault, often at dawn, to exploit surprise, Luftwaffe aircraft bombed command centers, communication lines, enemy artillery, and ammunition depots. Then tanks, with close air support, provided by Stukas and later Focke-Wulf 190 fighters, quickly passed through the gaps. Close coordination between tank and aircraft was made possible by radio.

Strategic bombers, such as America's B-17 Flying Fortress and Britain's Lancaster, also had long range, up to three thousand kilometers, and heavy bomb capacity, up to eight thousand kilograms. They could target enemy factories, railways, and cities. The Italian theorist Giulio Douhet argued in his book *Command of the Air*, 1921, that bombing enemy cities from the air would shatter civilian morale. The experience of the Second World War showed this theory to be exaggerated, civilian morale did not collapse under heavy bombing but grew angrier, but strategic bombing of industrial infrastructure, oil, steel, ball-bearing production, had a decisive effect on the outcome of the war.

Eyewitness testimony, from the margins of the Eastern Front, 1943, in the voice of the Stuka pilot Hans Rudel, rendered here in translation, recalls a mission to bomb a bridge over the Dnieper; the commander telling them that ground forces, Guderian's tanks, needed this bridge, and that if they did not destroy it, the enemy would reach their rear lines within twenty-four hours; diving from four thousand meters, the ground rushing up fast; the Stuka's sirens beginning to howl; anti-aircraft shells exploding all around; releasing a five-hundred-kilogram bomb at eight hundred meters and pulling up sharply; looking back to see the bridge engulfed in a cloud of smoke and fire; ground forces later telling him they crossed the bridge without any resistance; the writer says that day he understood that an aircraft could function as a mobile artillery piece, faster than any ground artillery. From the memoirs of the German pilot Hans-Ulrich Rudel, the most decorated dive-bomber pilot in history, credited with destroying 530 tanks.

The Maneuver of Encirclement and Annihilation (Kesselschlacht)

The new doctrines emphasized encirclement and annihilation, Kesselschlacht, cauldron battle, rather than mere linear advance. The idea was that mobile forces, tanks and motorized infantry, would pass around the enemy's flanks and meet behind him, encirclement, creating a cauldron that trapped the enemy's forces. Infantry forces would then gradually tighten the ring, forcing the enemy to surrender or be destroyed.

The encirclement of Kyiv, September 1941: Germany's First Panzer Group, General Ewald von Kleist, and Second Panzer Group, General Heinz Guderian, met from south and north and trapped 650,000 Soviet soldiers in a massive cauldron. Roughly six hundred thousand were captured.

The encirclement of Stalingrad, November 1942: the Soviet Union, Operation Uranus, encircled Germany's Sixth Army, General Friedrich Paulus, with three hundred thousand men. With supply lines cut and severe cold, minus thirty degrees, ninety thousand eventually surrendered.

Conditions for success: temporary air superiority, high tank speed, motorized infantry, and adequate supply.

Eyewitness testimony, from the margins of the encirclement of Stalingrad, 1942, in the voice of a German soldier, rendered here in translation, recalls thinking they were winning; suddenly, news arriving that the Russians had attacked from north and south and closed the ring of encirclement; supply cut off; ammunition running out; hunger pressing on them; the commander saying, we have fallen into a cauldron; the ring tightening every day; in January 1943, surrendering; ninety thousand of them taken prisoner; the writer says that from that day on he understood that encirclement is deadlier than any battle. From the memoirs of the German soldier Hans Eckhardt.

Effect on Fortifications and Cities

The new doctrines rendered linear fortifications, such as France's Maginot Line, obsolete. If a line of fortifications is broken at a single point, with concentrated armor and artillery, the entire line becomes useless. After the Second World War, linear fortification construction gave way to defense in depth: scattered fortified zones with minefields, artillery fire, and mobile reserve forces.

Cities, too, became important fortifications. In the Battle of Stalingrad, every house became a fortress. Soviet soldiers disabled German tanks with Molotov cocktails and anti-tank rifles. Urban warfare, in which tank armor was vulnerable in narrow streets, became a form of attritional combat.

The Legacy of the New Doctrines (from 1945 to Today)

The Six-Day War, 1967: Israel, with a preemptive strike on Egyptian air bases, gained air superiority and defeated the Egyptian and Syrian armies in six days.

The Gulf War, 1991: superiority in intelligence and firepower, satellites, GPS, smart bombs, destroyed the classical Iraqi army in one hundred hours.

But guerrilla wars showed that technological superiority alone is not enough. Asymmetric warfare, against an enemy hiding among civilians, presents a new challenge.

Today's military doctrines emphasize network-centric warfare: sensors provide real-time information, artificial intelligence makes decisions, and weapons fire with high precision. The goal is to shorten the OODA loop, observe, orient, decide, act.

Chapter Summary

Chapter Seventeen has shown that the new doctrines of war, by combining fast, radio-equipped tanks, supporting aircraft, dive bombers, and motorized forces, broke the deadlock of the static fronts of the First World War. Coordination among weapons, speed of execution, and concentration at the enemy's weak point mattered more than sheer firepower. In the next chapter, Air, Reconnaissance, and the Birth of the Third Dimension of War, we will see how air superiority became a necessary condition for the success of ground operations.

Chapter 18

Air, Reconnaissance, and the Birth of the Third Dimension of War

The Pivotal Moment: April 22, 1915, the Trenches of Ypres, Belgium

It was five in the afternoon. The German pilot Hans Krogel was flying his unarmed reconnaissance aircraft, an Albatros B.I, over enemy lines at 1,500 meters. His mission was simple: photograph the French trenches and correct artillery fire. In the first two years of the war, aircraft on both sides were unarmed, and pilots, on encountering one another, greeted each other with a wave. But today, something had changed. Suddenly, the French pilot Roland Garros dove his aircraft toward Krogel. Mounted on the nose of Garros's aircraft was something strange: a machine gun that fired through the propeller. Krogel watched in horror as bullets passed between the propeller blades and struck his aircraft's wing. He tried to flee, but his engine was damaged. The aircraft began to fall. Krogel threw himself out with his parachute. The French pilot flew past him and gestured. Below, French soldiers cheered and followed Krogel's parachute with joyful shouts. He was captured. A few days later, Garros himself crashed, and his aircraft fell into German hands. The Germans copied Garros's synchronization gear and mounted it on their new fighter, the Fokker Eindecker. This aircraft, which became known as the Fokker Scourge, dominated the skies of the Western Front for a full year. The age of the swords of the sky had begun.

Eyewitness testimony, from the margins of the air war in the west, 1915, in the voice of the German pilot Oswald Boelcke, one of Germany's air aces, rendered here in translation, recalls first seeing the Fokker Eindecker in August 1915; the aircraft small and agile, with a machine gun synchronized to the propeller; on his first mission with this

aircraft, shooting down a French reconnaissance biplane; not believing how easy it was to shoot; no longer needing a pistol or rifle; only needing to aim and pull the trigger; by December 1915, having shot down five enemy aircraft; German newspapers calling him an ace; but inside the cockpit, he says, he was only a twenty-four-year-old boy afraid of being killed at any moment.

From Ground to Sky: The First Steps

Before the twentieth century, the battlefield was confined to two dimensions: geographic length and width. Army commanders used natural high ground, hills, towers, and occasionally tethered balloons, to observe the enemy's formation, but this view was always limited, unclear, and dependent on physical position. The Industrial Revolution made flight possible.

The first hot-air balloons were built by the Montgolfier brothers in 1783. In 1794, the French revolutionary army used a balloon named *Entreprenant* to observe Austrian positions at the Battle of Fleurus. This was the first military use of a flying craft. Balloons were tethered to the ground by cable, and intelligence officers with binoculars observed enemy dispositions from an altitude of three hundred to five hundred meters. Even so, balloons were slow, vulnerable, an easy target for artillery, and dependent on wind.

Rigid airships, the Zeppelin, were built by Ferdinand von Zeppelin in Germany in 1900. These giants of the sky, with an aluminum skeleton and a fabric envelope, reached lengths of up to 240 meters and bomb capacities of up to two thousand kilograms. Zeppelins were used in the First World War for the strategic bombing of London and Paris, 1915 to 1916. Although their casualty toll was low, roughly five hundred killed across the entire war, they created widespread psychological terror. Even so, low speed, eighty to 110 kilometers per hour, vulnerability to fighters, filled with flammable hydrogen, and dependence on weather gradually pushed them from the battlefield.

The invention of the heavier-than-air aircraft by the Wright brothers, 1903, opened the gates of the third dimension to war. In the years before the First World War, armies used aircraft mainly as flying eyes for reconnaissance and artillery-fire correction. Pilots flew at low altitude, three hundred to a thousand meters, and recorded, with camera or map, the position of enemy trenches, artillery, and supply columns. At first, aircraft were unarmed, and pilots on both sides greeted each other with a wave or by throwing a brick. But very soon, a deadly rivalry began.

Aerial Reconnaissance: The Commander's Eyes

In the First World War, the value of aerial reconnaissance far exceeded that of any other weapon. Commanders needed precise aerial photographs of enemy lines to decide when and where to attack. Reconnaissance aircraft, such as Germany's Rumpler C.VII and Britain's BE.2, flew over the front with large cameras, up to fifty kilograms, taking hundreds of photographs. These photographs were analyzed by intelligence officers and revealed the position of trenches, fortifications, and enemy concentrations.

The first three-dimensional images, using two cameras shooting simultaneously, stereoscopy, were devised in the war's later years. These images let commanders estimate the depth of trenches and the height of fortifications. Correcting artillery fire was also one of the vital applications of aerial reconnaissance. Artillery officers used aircraft to correct their own fire. The pilot, observing where his own artillery's shells landed, radioed the error, in Morse code, to a ground operator. This reduced artillery error from several hundred meters to a few dozen.

At the Battle of Verdun, 1916, French aerial reconnaissance, by discovering the concentration of German artillery behind hills, allowed French commanders to arrange preemptive fire and neutralize German attacks. Marshal Pétain later said that their eyes in the sky had saved the lives of tens of thousands of soldiers. Even so, reconnaissance aircraft were also easy prey for enemy fighters. For this reason, the battle for air superiority carried a vital role from the very outset.

Eyewitness testimony, from the margins of the Western Front, 1916, in the voice of a French reconnaissance pilot, rendered here in translation, recalls his mission each morning: flying over German trenches, photographing their new positions, and returning; his altitude one thousand meters; one day a German Fokker Eindecker spotting him and beginning pursuit; having no weapon; his only chance, speed; diving toward the ground; bullets striking his wings; hearing the sound of tearing fabric; at fifty meters, reaching his own lines; making an emergency landing; afterward

counting twelve bullet holes in his aircraft; the writer says that day he understood that reconnaissance without protection is suicide. From the memoirs of the French pilot Antoine de Saint-Exupéry, later the author of *The Little Prince*.

The Birth of the Fighter: Duel in the Sky

To prevent enemy reconnaissance, both sides began to think of hunters of the sky. Fighter aircraft were light, fast, and armed with machine guns. The first aerial engagements, in 1914, involved pilots firing pistols and rifles at one another, but with little effect. Pilots then began carrying bricks, chains, and even knives to damage an enemy's propeller.

The synchronization gear was the final solution. This technology allowed a machine gun to fire through the propeller without damaging its blades. This invention, built by the Dutch engineer Anthony Fokker for the Germans in 1915, transformed aerial warfare forever. The Fokker Eindecker was the first successful fighter with a synchronized machine gun. This aircraft dominated the skies of the west from the autumn of 1915 to the spring of 1916 and became known as the Fokker Scourge. Allied pilots, French and British, lacked this technology for a full year afterward and were extremely vulnerable to it.

Fighters gradually became specialized. The Germans developed the Albatros, with two synchronized machine guns and a powerful engine, and the Fokker Dr.I triplane, with exceptional agility, known as the Red Baron's aircraft. The British built the S.E.5, the Sopwith Camel, with extraordinary agility, and later the Spitfire. The French, too, fielded the fast Nieuport and Spad aircraft.

Aerial combat tactics included dive and zoom, in which a pilot dove on the enemy from higher altitude, fired several bursts, and then, using the kinetic energy gained, climbed back to altitude. In a turning fight, if the enemy managed to evade, the battle became a turning contest, in which the more maneuverable aircraft held the advantage. The Germans devised the pair tactic, *Rotte*, in which two aircraft, leader and wingman, covered one another, and later expanded it into the finger-four, *Schwarm*.

Elite pilots became known as aces, those who recorded five or more aerial victories. The most famous were Manfred von Richthofen, the Red Baron, German, with eighty victories, René Fonck, French, with seventy-five victories, Edward Mannock, British, with seventy-three victories, and Eddie Rickenbacker, American, with twenty-six victories. The average lifespan of a British fighter pilot in 1917 was only two weeks.

Eyewitness testimony, from the margins of the Western Front, 1917, in the voice of the German pilot the Red Baron, Manfred von Richthofen, rendered here in translation, recalls flying at three thousand meters, the sun behind him; suddenly spotting a French Spad below; diving; closing at three hundred kilometers per hour; at fifty meters, pulling the trigger; a short burst, three seconds; seeing the French pilot slump backward and the aircraft begin to fall; climbing back up; glancing down; the pilot's parachute opening; the pilot alive; gesturing to him and returning to base; his twenty-eighth victory; but no joy in it, only another number in his notebook.

Aerial Bombardment: From Hand-Dropped Bombs to Mass Killing

The first aerial bombardment was carried out by the Italians in Libya, November 1911: the pilot threw small bombs out of the aircraft by hand. In the First World War, specialized bombers were built. Light, tactical bombers were used to support ground forces with fragmentation bombs, targeting trenches and supply columns. Heavy, strategic bombers, such as Britain's Handley Page and Germany's Gotha, with bomb capacities of up to five hundred kilograms, flew by night over London, Paris, and German cities, dropping bombs on residential areas.

The target of these attacks was not factories, but the will to resist of civilians. In 1918, London was bombed several times and hundreds of civilians were killed. British media called these attacks German savagery. But the British themselves had also bombed German cities. These were the first signs of total war, war in which women and children too are targeted.

The Italian theorist Giulio Douhet argued in his book *Command of the Air*, 1921, that strategic bombing of enemy cities, without need of a ground army, could force an enemy to surrender. The experience of the Second World War

showed this theory to be exaggerated, but strategic bombing of industrial infrastructure, oil, steel, ball-bearing production, had a decisive effect on the outcome of the war.

Balloon and Zeppelin: The First Stable Platforms

Balloons tethered to the ground by cable served as tall eyes for observing enemy lines. In the First World War, both sides used observation balloons, heavily protected by anti-aircraft units and fighters. Balloons were made of fire-resistant material, kite balloons, and filled with hydrogen gas. Bringing down a balloon was not easy owing to its stability, but fighter pilots attacked balloons to record a special kind of victory.

Zeppelins, Germany's rigid airships, were strategic bombers that could fly at four thousand meters with a range of two thousand kilometers. The bombing of London and Paris by Zeppelins in 1915 and 1916 created terror, but casualties were low, roughly five hundred killed across the whole war. Zeppelins were slow, vulnerable to fighters, and carried large quantities of highly flammable hydrogen gas. After the British developed incendiary rounds for downing Zeppelins, this weapon was quickly abandoned.

Anti-Aircraft Fire and the Defense of the Sky

As the aerial threat grew, anti-aircraft weapons developed. Light anti-aircraft guns, twenty to forty millimeters, with a high rate of fire, up to 250 rounds per minute, and firing tracer rounds, were built to counter low-altitude aircraft. Heavy guns, seventy-five to 105 millimeters, were designed for high-altitude aircraft, bombers, but the low accuracy of anti-aircraft fire was the main problem: thousands of rounds were fired to hit a single aircraft, an average of four thousand rounds per target. Proximity fuze technology was developed in the Second World War and dramatically increased the effectiveness of anti-aircraft fire, since the shell detonated automatically near the target. Searchlights, for detecting night aircraft, and radar, Radio Detection And Ranging, for identifying aircraft from long distances, up to two hundred kilometers, were other tools of air defense. Britain, with its Chain Home radar system, was able to detect German air attacks in the Battle of Britain, 1940, and win.

Transformation in Tactics and Doctrine Between the Wars

After the First World War, theorists such as Billy Mitchell, United States, and Hugh Trenchard, Britain, advocated the creation of an independent air force. This thinking led to the independence of Britain's Royal Air Force in 1918 and of the United States Air Force in 1947. In Germany, Hermann Göring organized the air force, the Luftwaffe, as a fully independent branch, but in coordination with blitzkrieg.

Technical developments were remarkable: all-metal aircraft with more powerful engines, one thousand horsepower, enclosed cockpits, for flight at high altitude and in harsh conditions, propeller-synchronized machine guns, dive bombers, the Stuka, and four-engine strategic bombers, the B-17, the Lancaster, were among these developments.

Strategic Consequences: Air Superiority as a Necessary Condition

In the Second World War, air superiority, the ability to operate freely in the sky and deny the enemy the same, became a necessary condition for any major ground or naval operation.

The Battle of Britain, 1940, was the first battle fought entirely in the sky, with the goal of achieving air superiority. Germany, with 2,600 aircraft, mainly bombers and fighters, faced Britain, with 750 fighter aircraft, Spitfires and Hurricanes. Britain, using radar, the Chain Home system, superior fighters, the Spitfire with excellent high-altitude performance, and skilled pilots, was able to defeat the Luftwaffe. Winston Churchill, in his famous speech, said that never in history had so much been owed by so many to so few. He meant Britain's fighter pilots.

After the Second World War, jets replaced piston engines. Aircraft reached the speed of sound, such as the F-86 and MiG-15, and then supersonic speed, the F-104, the MiG-21. Strategic bombers became capable of carrying nuclear weapons. Guided missiles, air-to-air and air-to-ground, extended the engagement distance from a few hundred meters, the machine gun, to several dozen kilometers, the missile. Helicopters, such as the Huey, transformed the mobility of ground forces. Drones now play a decisive role in reconnaissance and precision strikes, while air superiority today is

impossible without a chain of AWACS aircraft, airborne warning and control, aerial refueling tankers, and reconnaissance satellites.

Eyewitness testimony, from the margins of the Battle of Britain, 1940, in the voice of an unnamed English pilot, rendered here in translation, recalls flying a Spitfire; the Germans coming with one hundred bombers and fifty Messerschmitts; spotting a Messerschmitt behind one of the bombers; diving; at two hundred meters, pulling the trigger; eight machine guns firing at once; seeing the Messerschmitt catch fire and fall toward the ground; the pilot bailing out with his parachute; looking around; seeing three of his friends going down; no time to think, no time for fear, only to fight; returning to base once ammunition ran out; fourteen bullet holes in his aircraft; on the ground, the squadron commander telling him, you fought well, but tomorrow you must go up again.

Chapter Summary

Chapter Eighteen has shown that the arrival of air power on the battlefield transformed war from a two-dimensional to a three-dimensional arena. Aerial reconnaissance enabled commanders to observe enemy formations from above and direct their fire with unprecedented precision. Aerial bombardment placed the rear areas at risk as well, targeting civilians. Fighters fought fiercely for air superiority, and whoever controlled the sky could destroy both land and sea forces as well. Even so, air power never fully replaced ground forces. In the end, seizing territory required the presence of infantry soldiers on the ground. But air superiority guaranteed their success and reduced their casualties. In the next chapter, Fighter Aircraft, Air Superiority, and the Myth of the Pilot, we will examine the culture and psychology of aerial combat and the legend of the elite pilot.

Chapter 19

Fighter Aircraft, Air Superiority, and the Myth of the Pilot

The Pivotal Moment: September 15, 1940, the Skies over London, Britain

It was 11:30 in the morning. The English pilot John de Salis was flying his Spitfire at six thousand meters over London. Below him, the Thames gleamed like a silver ribbon. Suddenly, black dots appeared on the eastern horizon. Twenty German Heinkel He 111 bombers, escorted by thirty Messerschmitt Me 109 fighters, were approaching the British capital. The radio in his cockpit crackled: all squadrons, scramble. The enemy is approaching.

De Salis's hands trembled on the joystick. Eight Browning machine guns in the Spitfire's wings waited for the command. He dove toward the enemy. A Messerschmitt grew large before his eyes. He squeezed the trigger. Eight streams of fire poured into the German fighter. He saw the Messerschmitt catch fire and fall toward the ground. But before de Salis had a chance to celebrate, another Messerschmitt fired at him from behind. Bullets punched through his cockpit. The scream of the engine and the wind pouring through the holes tore at his ears. De Salis tried to escape. With all his strength, he pulled the joystick to the left. The aircraft, in a violent turn, left the enemy behind. Through fog and smoke, he made it home. On the ground, the crew counted thirty-four bullet holes in his Spitfire's body. Survivors of the Battle of Britain later said, that day I recorded only one victory. But what mattered was that I survived. Every morning, we looked up at the sky, knowing we might never return. But we went up anyway. Because if we hadn't, the Germans would have taken London. The Battle of Britain reached its peak on September 15, 1940, and the Luftwaffe, Germany's air force, was forever denied dominance over British skies. Churchill, in his famous speech, said that never in the field of human conflict had so much been owed by so many to so few.

Eyewitness testimony, from the margins of the Battle of Britain, 1940, in the voice of an English pilot known only as Bridget, rendered here in translation, recalls flying a Spitfire; the Germans coming with one hundred bombers and fifty Messerschmitts; spotting a Messerschmitt behind one of the bombers; diving; at two hundred meters, pulling the trigger; eight machine guns firing at once; seeing the Messerschmitt catch fire; the pilot bailing out with his parachute; looking around; seeing three of his friends going down; no time to think, no time for fear, only to fight; returning to base once ammunition ran out; fourteen bullet holes in his aircraft; on the ground, the squadron commander telling him, you fought well, but tomorrow you must go up again.

From Eyes of the Sky to Swords of the Sky

In the early days of aerial warfare, aircraft were mostly unarmed, and their role was confined to reconnaissance and artillery-fire correction. Pilots on both sides sometimes fired pistols, rifles, or even bricks at one another, but these actions were more symbolic than effective. Even so, the need to prevent enemy reconnaissance quickly turned pilots and engineers toward weapons. The first solutions were mounting a machine gun on the upper wing, which made changing magazines and clearing jams difficult, or on the fuselage, which fired through the propeller and damaged the blades. The final solution was the synchronization gear, which allowed a machine gun to fire through the propeller blades, precisely at the moment the blade was not in front of the barrel. This invention, built by Anthony Fokker for the Germans in 1915, transformed aerial warfare forever. From that moment, aircraft turned from eyes of the sky into swords of the sky.

Aerial Aces: The Birth of the Pilot Legend

In ground wars, soldiers were anonymous and nameless. But in aerial warfare, pilots quickly became stars. Newspapers reported the victories of aerial aces with dramatic detail. People knew the names of pilots such as the Red Baron, Germany, eighty victories, René Fonck, France, seventy-five victories, Edward Mannock, Britain, seventy-three victories, and Eddie Rickenbacker, America, twenty-six victories. These aces flew personal aircraft, with distinctive colors and special markings, and were presented in war propaganda as models of courage.

The pilot legend served several functions: covering over the horror and meaninglessness of trench warfare, drawing young men to the air force, and creating a sense of competition and national pride. Even so, reality fell short of the legend: most pilots, roughly eighty percent, never achieved a single aerial victory and were themselves shot down. Aces made up only about five percent of pilots, but were responsible for more than fifty percent of kills, a Pareto distribution. Ace pilots often had extraordinary vision, up to 20/10, twice that of an ordinary person, fast reaction time, under 0.2 seconds, and the ability to make decisions under critical conditions, high situational awareness.

Eyewitness testimony, from the margins of the Western Front, 1918, in the voice of the American pilot Eddie Rickenbacker, rendered here in translation, recalls seeing a German Fokker Dr.I chasing a French Spad; diving; his two machine guns opening fire; not knowing how many rounds he fired, but suddenly the Fokker catching fire and beginning to fall; the German pilot bailing out of the cockpit; his parachute failing to open; falling and dying; that night, unable to sleep; remembering that pilot's face; never having seen his face, but feeling he knew him; both of them merely soldiers, both merely defending their homelands.

Technology and Tactics in the Second World War

Between the two world wars, fighters underwent enormous transformation: wings went from wood and fabric to all-metal, engines rose from one hundred to one thousand horsepower, speed increased from two hundred to six hundred kilometers per hour, and service ceiling rose from five thousand to ten thousand meters. Radio became standard on all combat aircraft, and the pair tactic, *Rotte*, became the dominant approach.

The Battle of Britain, 1940, reached its peak in daily bombing by Germany, with Ju 87 Stuka and He 111 bombers, and defense by Britain, with Spitfires and Hurricanes. German pilots, with aircraft armed with heavy cannon to break up bombers, and American pilots, with the P-51 Mustang, a long-range fighter with a range of 1,650 kilometers with drop tanks, for escort, entered the fray. The P-51, owing to its long range and excellent high-altitude performance, could escort American bombers deep into Germany and seize the aerial initiative from the Luftwaffe.

On the Eastern Front, German fighters, the Me-109, the Fw-190, faced Soviet fighters, the La-5, the Yak-9, and later the La-7. Aerial battles were often fought at low altitude, in support of ground forces. Soviet pilots were initially weak, but with experience and better aircraft, gradually came to dominate the eastern skies.

The Pilot Legend in the Second World War

The Second World War, too, produced prominent aerial aces: Erich Hartmann, Germany, with 352 victories, a world record, Ivan Kozhedub, the Soviet Union, with sixty-two victories, and Richard Bong, the United States, with forty

victories in the Pacific. Hartmann earned most of his victories on the Eastern Front with the Me-109. His tactic was see, decide, attack, escape, and he never entered combat unless he held a positional advantage.

In Japan, kamikaze pilots, divine wind, who emerged in late 1944, created another legend: total sacrifice for the emperor. Kamikaze units, the Shinpu Tokubetsu Kogekitai, were formed in 1944, and young pilots, seventeen to twenty-four years old, crashed aircraft laden with bombs, 250 to five hundred kilograms, into American ships. Roughly 3,800 kamikaze pilots lost their lives, sinking or damaging thirty-four American ships.

In Britain, the Spitfire pilots of the Battle of Britain were celebrated as the elite and the saviors of the island. Winston Churchill, in his famous speech, August 20, 1940, said that never in the field of human conflict had so much been owed by so many to so few, meaning the fighter pilots. These legends helped strengthen national morale and drew volunteers to the air forces.

Even so, the reality of aerial warfare was far more brutal than the romantic image. The bombing of cities, Hamburg, Dresden, Tokyo, killed hundreds of thousands of civilians. Fighters, too, systematically attacked columns of refugees, trains, and even fishing boats. Pilots who bailed out with a parachute were sometimes targeted in the air, contrary to the Geneva rules, but in practice common on the Eastern Front. Fear of the aircraft catching fire and burning alive caused chronic stress among pilots. Over the course of the war, roughly 250,000 pilots from various countries lost their lives.

Eyewitness testimony, from the margins of the Pacific, 1945, in the voice of an American pilot, rendered here in translation, recalls escorting an aircraft carrier; suddenly, a Japanese Zero appeared out of the clouds, but not heading toward them, diving straight toward the carrier; firing at it; its left wing catching fire; but it continuing its dive; striking the carrier's deck; a massive explosion; two hundred killed; the Japanese pilot having crashed his aircraft into the carrier, a kamikaze; the writer says that day he understood that a person could give so much for his country that he would sacrifice himself; that he never had such courage; that he was only a soldier.

The Jet Age and the End of the Individual Duel

The emergence of jet aircraft in the closing years of the Second World War, Germany's Me-262, Britain's Gloster Meteor, and their dominance in the Korean War, the Soviet MiG-15 against America's F-86 Sabre, ushered in a new age. Supersonic speed and a service ceiling of fifteen thousand meters created a need for highly trained pilots and complex equipment, radar, inertial navigation, ejection seats. Radar allowed a pilot to detect the enemy from fifty kilometers away, and guided missiles, such as the Sidewinder, made engagement possible from several kilometers. The one-on-one machine-gun duel became missile fire from a distance. As a result, individual pilot skill lost some of its importance. Even so, the pilot legend persisted, since aerial warfare still required human decision-making under critical conditions, choosing to flee or pursue, managing ammunition and fuel.

In the Vietnam War, 1965 to 1973, American pilots, with the F-4 Phantom II, faced Soviet-Vietnamese MiGs, the MiG-17, the MiG-19, the MiG-21. Early missiles, the AIM-7 Sparrow and the AIM-9B, were unreliable at close range, and pilots were forced to rely on twenty-millimeter cannon. This experience showed that close combat, the dogfight, had not yet been removed from the battlefield. The new generation of fighters, the F-15, the F-16, the MiG-29, the Su-27, designed in the 1970s and 1980s, placed renewed emphasis on maneuverability and pilot visibility.

Chapter Summary

Fighter aircraft and their pilots created a legend unparalleled in the history of war. While infantry died in trenches and remained nameless, millions of anonymous dead, pilots, with a few dozen victories, were celebrated as national heroes. Media, governments, and artists, in literature, film, painting, built an image of the knight of the sky that continues today in films such as *Wings*, 1927, and *Top Gun*, 1986 and 2022, and in video games. Even so, the reality of aerial warfare, fear of catching fire, of burning, of sudden death, of watching friends fall every day, was never erased from the memory of surviving pilots.

With the operational arrival of stealth aircraft such as the F-117, 1983, autonomous drones, the Global Hawk, 2001, and fifth-generation fighters, the F-22, the F-35, even the pilot has moved from the cockpit to a control room thousands of kilometers away, in the case of drones. Is this the end of the age of the pilot legend? Perhaps. But the important

point is that even in the age of drones, a human still remains in the final decision-making loop for firing, at least before the emergence of full artificial intelligence. Even so, the growing trend of automation and artificial intelligence suggests that in the future, the pilot may become a supervisor who intervenes only in critical conditions. The pilot legend, like the propeller aircraft themselves, is becoming part of the romantic history of war, while the reality of the future battlefield will be cold and faceless.

Fighter Generations

Introduction: Why Generational Classification Matters

Generational classification of fighter aircraft is an informal but very common method of categorization in military, aerospace, and specialized media circles. This method helps specialists and enthusiasts understand the rapid progress of aviation technology from the golden age of jets to today. Each generation is the product of a leap in one or more key areas: propulsion, engine and aerodynamics, avionics, electronic systems and displays, radar and sensors, weapons, especially long-range and precision missiles, and stealth. Newer generations also increasingly rely on information synergy and network-centricity.

It should be noted that this classification is rooted mainly in Western, American and NATO, thinking. Russia and China sometimes shift the boundaries or call their fighters generation four-plus-plus or four-plus. But here, for clarity, we use the internationally accepted standard, covering the first through sixth generations.

First Generation (Mid-1940s to Mid-1950s): The Dawn of the Jet Age

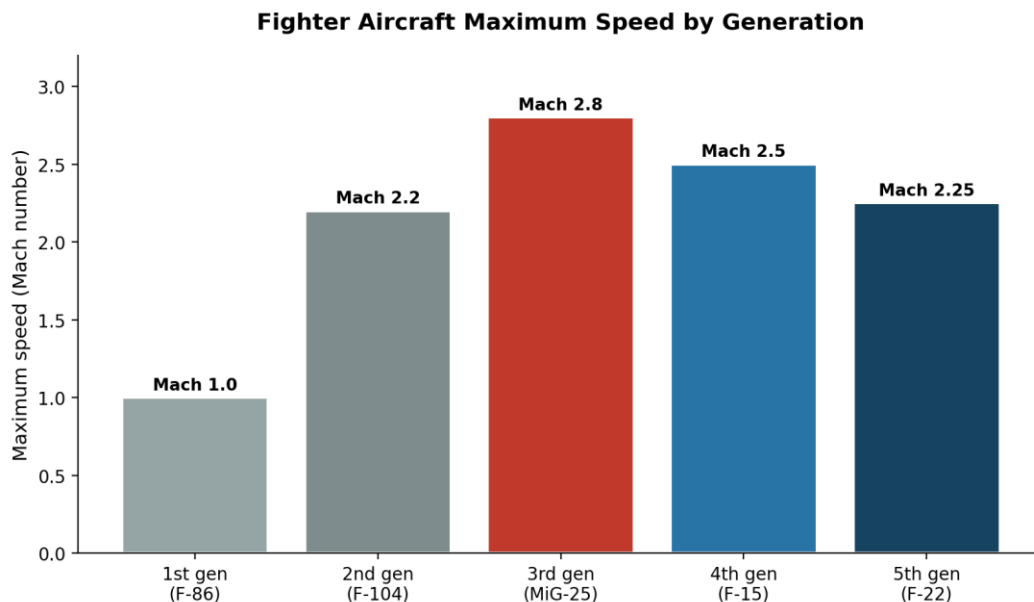


Chart: Maximum speed of representative fighter aircraft by generation (author's diagram, illustrative).

The first generation begins with the end of the Second World War and the emergence of the first operational jets. Nazi Germany, with the Messerschmitt Me 262, pioneered this age, though this fighter arrived too late to change the outcome of the war. After the war, the victorious powers, especially the United States and the Soviet Union, moved rapidly toward jet production.

Technical Features

A simple turbojet engine with a rudimentary afterburner, or none at all. Engines used axial or centrifugal compressors with high fuel consumption and weak acceleration. A swept-wing fuselage to reduce aerodynamic drag at transonic speeds. This design drew on German research at war's end. A straight wing, as in the early Lockheed P-80 Shooting Star, caused severe buffeting near the sound barrier. Very rudimentary radars, often just a simple short-range radar antenna, up to ten to fifteen kilometers, capable of detecting a target only as a point of light without precise altitude or speed data. The pilot had to visually search for the target, and radar offered only a simple confirmation. Primary weapons: cannon and machine guns, usually four to six 12.7-millimeter machine guns, Browning M2, or twenty- to thirty-millimeter cannon, such as the Hispano-Suiza cannon in British aircraft or the NR-23 cannon in Soviet MiGs. Unguided rockets, HVAR, were occasionally mounted under the wing. Simple analog avionics, no digital displays;

the pilot worked with dial gauges and warning lights. The flight control system was fully mechanical, with steel cables. Early ejection seats, often explosive or mass-driven types, effective only at moderate altitudes and speeds.

The Most Important First-Generation Fighters

The Me 262, Germany: the world's first operational jet, with two Jumo 004 engines. Speed roughly 870 kilometers per hour, armed with four thirty-millimeter MK 108 cannon. Used in intense aerial battles against B-17 bombers.

The F-80 Shooting Star, United States: America's first combat jet, used in the Korean War. Had a straight wing that limited its speed to below Mach 1. Performed acceptably against the MiG-15 but was soon outclassed.

The F-86 Sabre, United States: one of the most important first-generation jets, with a swept wing, thirty-five degrees. Achieved a slight edge over the MiG-15 in the Korean War. Equipped with the simple A-1CM radar and 12.7-millimeter machine guns, later twenty-millimeter cannon.

The MiG-15, Soviet Union: Korea's great surprise. Drawing on German technology, with a sturdy airframe, a thirty-seven-millimeter cannon, and the simple RP-1 radar. Owing to a good thrust-to-weight ratio, had a higher service ceiling than the F-86. Its main weakness was its engine, copied from the Rolls-Royce Nene.

The MiG-17, Soviet Union: an evolution of the MiG-15 with a more sharply swept wing, forty-five degrees, and improved maneuverability. Used in Vietnam and the Arab-Israeli wars, and despite its age, succeeded in downing more modern F-4s.

The Gloster Meteor, Britain: the Allies' second operational jet. Used mainly to intercept German V-1 bombs and later in a ground-attack role.

Combat Tactics

In the first generation, aerial combat still depended heavily on cannon. Pilots had to maneuver close to reach the target. The first jet battles of the Korean War, 1950 to 1953, showed that high speed was a decisive advantage, but maneuverability and visual detection were still key. In this period, guided air-to-air missiles effectively did not exist.

Second Generation (Mid-1950s to Early 1960s): The Arrival of Missiles and Pulse Radar

The second generation witnessed a revolution in the concept of aerial combat. Military theorists believed the age of the cannon had ended and that guided missiles would determine everything. This belief led many second-generation fighters to be built without an internal cannon, such as the early F-4 Phantom, a mistake that later proved costly in the Vietnam War.

Technical Features

Pulse radar with an effective range of twenty to fifty kilometers. These radars could measure the range and angle of a target but were helpless against ground clutter. As soon as a target dropped below the horizon or near mountains, the radar lost it. This limitation forced pilots to intercept targets from above, looking up, and never look down. The first guided air-to-air missiles: infrared, IR, missiles such as the AIM-9B Sidewinder, which followed the infrared radiation of an enemy engine. Early versions were effective only from behind and at a range of two to three kilometers and could easily be defeated by a simple maneuver. Semi-active radar homing, SARH, missiles such as the AIM-7 Sparrow, which required the aircraft's radar to continuously illuminate the target to maintain lock. Range up to ten kilometers, but low reliability, under ten percent hit rate under real wartime conditions. Speed increased to the Mach 2 barrier, with slender fuselage designs and more powerful engines, such as the General Electric J79. Aircraft such as the F-104 Starfighter and the MiG-21 could reach Mach 2, but at a great cost to maneuverability. Cannon were pushed to the margins; some models, the early F-4, had no cannon at all and carried only missiles. Later, they recognized their mistake and added a cannon, the M61 Vulcan, in a pod or externally. Zero-zero ejection seats: in the late second generation, seats appeared that could save a pilot even on the ground at zero speed.

The Most Important Fighters

The F-100 Super Sabre, United States: the world's first supersonic fighter, Mach 1.3 at sea level, but used more in an attack role than for air superiority. Proved vulnerable in the Vietnam War.

The F-104 Starfighter, United States, Italy, Germany: with a missile-like fuselage and very small trapezoidal wings. High speed, Mach 2.2, with an astonishing climb rate, but terrible maneuverability and a high accident rate. Became known as the widowmaker.

The MiG-19, Soviet Union: the Soviet Union's first Mach 2 jet, with two engines. Mass-produced in China as the J-6. Achieved modest results against the F-4 in Vietnam.

The MiG-21, Soviet Union: the most-produced supersonic fighter in history, more than eleven thousand units. Simple, cheap design, with a single Tumansky R-11 engine and a delta wing. Speed Mach 2.0, good acceleration, but poor rear visibility and high wing loading. Served in more than fifty countries for decades.

The Mirage III, France: Europe's first supersonic fighter with a delta wing. Simple radar, good range, and a sturdy structure. Used successfully by Israel in the Six-Day War and the Yom Kippur War.

The Saab 35 Draken, Sweden: a unique double-delta design offering both good maneuverability and high speed. Equipped with Sweden's first IR missile, the RB 28.

Critical Limitations Exposed in the Vietnam War (1965 to 1973)

Vietnam's air battles showed that early second-generation missiles were highly unreliable. The AIM-7 Sparrow struggled to lock in humid conditions and high-g maneuvers. The AIM-9B was effective only from behind. American pilots with the cannon-less F-4 were forced to close with the enemy and maneuver until the missile locked, something the F-4, owing to its multi-role design, did poorly. North Vietnam's MiG-17s and MiG-21s, with two heavy cannon, held the advantage in close combat. Result: the United States was forced to reinstall the cannon and take BVR, beyond-visual-range, tactics seriously.

Third Generation (Early 1960s to Early 1970s): Look-Down Radar and Better Missiles

The third generation was a direct attempt to solve Vietnam's problems. Designers now understood that not only speed but stable maneuverability, radar resistant to ground clutter, and reliable missiles were essential.

Technical Features

Pulse-Doppler radar, an enormous leap. This radar could filter out stationary targets, mountains, buildings, trees, and display only moving targets. For the first time, a pilot could look down and fire at a target below the horizon, shoot-down. Effective range reached fifty to one hundred kilometers. A prime example: the AWG-10 radar on the F-14, late third generation. Third-generation missiles: the AIM-9G/H Sidewinder, with limited all-aspect interception and a range of five to eight kilometers; the AIM-7E-2 Sparrow, with improved reliability, thirty percent hit rate under real conditions, and a range of fifteen kilometers; Russia's R-23, AA-7 Apex, and R-60, AA-8 Aphid, with more sensitive infrared seekers. Optimized maneuverability: fighters were no longer simply flying missiles. Airframe design aimed for a thrust-to-weight ratio above one and wing loading below three hundred kilograms per square meter. The MiG-23, with a variable-sweep wing, could land well at low speed and have low drag at high speed. More sophisticated avionics: radar warning receivers, RWR, such as the APR-25, appeared, telling a pilot who had locked onto him and from what angle. First attempts at simple radar displays in the cockpit, rather than just a single dot. Early electronic warfare: chaff, aluminum strips, and flare dispensers, artificial heat sources, to deceive radar and heat-seeking missiles.

The Most Important Fighters

The F-4 Phantom II, United States: though its roots trace to the second generation, later versions, the F-4E and F-4J, can be considered third generation. With an internal twenty-millimeter cannon, pulse-Doppler radar, APQ-120, and

improved missiles, performed far better in late Vietnam and the 1973 Arab-Israeli wars. More than five thousand units were produced.

The MiG-23, Soviet Union: the Soviet Union's first variable-sweep-wing fighter. Speed Mach 2.35, the High Lark radar, Sapfir-23, with a range of forty kilometers and look-down capability. Served in Syria, Iraq, Libya, and Angola. Its maneuverability was lower than the F-16's, but it performed well as an interceptor.

The F-111 Aardvark, United States: though mostly a tactical bomber, its variable-sweep wing, terrain-following radar, and side-by-side two-seat cockpit were among third-generation innovations. Used in Vietnam for low-altitude penetration.

The Mirage F1, France: successor to the Mirage III, with a swept wing, not delta, and improved radar. Better maneuverability and greater range. Performed acceptably in the Western Sahara conflicts and the Iran-Iraq war.

Tactical Achievements

The third generation, for the first time, conducted effective BVR battles. In the 1973 Arab-Israeli war, F-4Es downed MiG-21s from a distance of twenty kilometers using the AIM-7E missile. Yet close combat, the dogfight, still predominated, and various tactics such as the Fallon Maneuver and the Lufbery Circle, energy-maneuverability tactics, reached their peak.

Fourth Generation (Mid-1970s to 1990): The Digital Revolution and Multi-Role Capability

The fourth generation is without doubt the longest and most diverse period of fighter design. To this day, most of the world's air forces, more than eighty percent, consist of fourth-generation fighters or their improved four-point-five versions. This generation saw the birth of fly-by-wire, glass cockpits, advanced Doppler radars, and remarkable weapons.

Foundational Features

Fly-by-wire flight control: the complete elimination of mechanical cables, replaced by electronic signals. This technology allowed designers to build inherently unstable aircraft, relaxed static stability. Result: astonishing maneuverability without fear of loss of control. The first fighter with full fly-by-wire was the F-16 Fighting Falcon, which, owing to its deliberate instability, could maneuver at a twenty-five-degree angle of attack, while the F-4 stalled at fifteen degrees. The all-glass cockpit: instead of dial gauges, color multi-function displays, MFDs, that could show a map, radar image, weapon status, and sensor data as the pilot chose. The HOTAS system, hands on throttle-and-stick, let a pilot execute every command without taking a hand off the throttle or the stick. Digital Doppler and PESA radar: the late fourth generation saw the emergence of passive electronically scanned array, PESA, radars, which scanned without physically moving the antenna. Radar range reached 150 to two hundred kilometers, with track-while-scan capability for multiple simultaneous targets.

Advanced Weapons

The AIM-120 AMRAAM, the first active-radar fire-and-forget missile, with a range of fifty to one hundred kilometers, inertial guidance plus active radar in the terminal phase. A pilot could disengage after firing. The AIM-9L/M Sidewinder, a third-generation heat-seeking missile with all-aspect capability and a range of ten to fifteen kilometers, resistant to simple flares. Smart bombs, the GBU-10/12, with laser or GPS guidance, JDAM in later versions.

Composite materials: the use of carbon and composites in the airframe, up to thirty percent of weight, to reduce weight and increase strength.IRST sensors, infrared search and track, as a complement to radar for attacking without activating radar.

Notable Fourth-Generation Fighters

The F-14 Tomcat, United States: defender of aircraft carriers. A massive variable-sweep wing, the AWG-9 radar with a range of three hundred kilometers, for intercepting long-range bombers, and AIM-54 Phoenix missiles with a range of 180 kilometers, a weapon that, in the Americans' own words, was itself practically an aircraft. Made famous by the film *Top Gun*. Retired in 2006.

The F-15 Eagle, United States: designed with the goal not one kilogram for ground attack, only air superiority. With an extraordinary thrust-to-weight ratio, above 1.2, and two F100-PW-100 engines, could reach ten thousand meters in thirty seconds. Holds a record of 104 aerial victories without a single loss in combat, Israel, Saudi Arabia. Later, the F-15E Strike Eagle version became a multi-role attack fighter.

The F-16 Fighting Falcon, United States: the cheap, maneuverable Viper. The first aircraft with fly-by-wire and an unstable design. Wing loading of only 430 kilograms per square meter. Owing to its bubble canopy and thirty-degree reclined seat, offers excellent pilot visibility. More than 4,500 units in twenty-five countries. Despite its small size, capable of carrying nine tons of ordnance, more than the Second World War's B-17 bomber.

The F/A-18 Hornet, United States: a twin-engine carrier-based fighter with a swept wing and twin tails. True multi-role, fighter/attack, capability. The APG-65 radar with a range of 150 kilometers. Replaced the A-7 and F-4 in naval service.

The MiG-29 Fulcrum, Soviet Union: designed to counter the F-16. Two powerful engines, a blended wing, good cockpit visibility. The N019 radar with a range of seventy kilometers. Weakness: short range, only 1,500 kilometers on maximum internal fuel, and analog avionics. The later MiG-29M version was upgraded to generation 4.5.

The Su-27 Flanker, Soviet Union: the Soviet answer to the F-15. Large, long range, 3,500 kilometers, super-maneuverable, capable of performing the Pugachev's Cobra, a 120-degree angle of attack without losing control. The N001 radar with a range of 150 kilometers. The Su-27 family, the Su-30, Su-34, Su-35, Su-37, forms the backbone of Russian and Chinese air power.

The Mirage 2000, France: a delta wing with fly-by-wire. Simple, light, capable of carrying a tactical nuclear weapon. Serves in India, Greece, and the United Arab Emirates.

Generation 4.5 (Mid-1990s to 2020): A Bridge to the Fifth Generation

Generation 4.5 refers to fighters upgraded within the same fourth-generation airframe, but with improved avionics, radar, and a relative reduction in radar cross section, stealth-lite. Features: AESA radar, active electronically scanned array, with no mechanical movement, thousands of small transmit-receive modules. Range 250 to four hundred kilometers, with the ability to track dozens of targets simultaneously and conduct offensive electronic warfare. Reduced radar cross section: the use of radar-absorbent coating, aligned-edge design, and placing weapons in semi-internal bays, though not fully internal. Cross section reduced from ten to twenty square meters to 0.5 to one square meter. Sensor fusion: integrating radar,IRST, RWR, and data-link information into a single image. Europe's Meteor missile: a long-range radar-guided missile with a ramjet, Mach 4-plus and a range of 150-plus kilometers.

The main 4.5-generation fighters: the F/A-18E/F Super Hornet, United States, larger, with AESA, more fuel capacity, and two stealthy pylons for missiles; the F-15EX Eagle II, United States, the newest F-15 version, with AESA, external weapons bays, and the capacity to carry twenty-two missiles; the Su-35S, Russia, a fundamental upgrade of the Su-27 with the Irbis-E radar, PESA but powerful, engines of 345 kilonewtons, and super-maneuverability; the Dassault Rafale, France, delta-canard, AESA, the Meteor missile, nuclear capability; the Eurofighter Typhoon, Europe, a four-nation design, the CAPTOR radar, super-maneuverable; and the J-10C, China, an AESA version of the J-10, with PL-15 missiles, a range of two hundred kilometers.

Fifth Generation (Late 1990s to Early 2020s): The Age of Stealth and Full Awareness

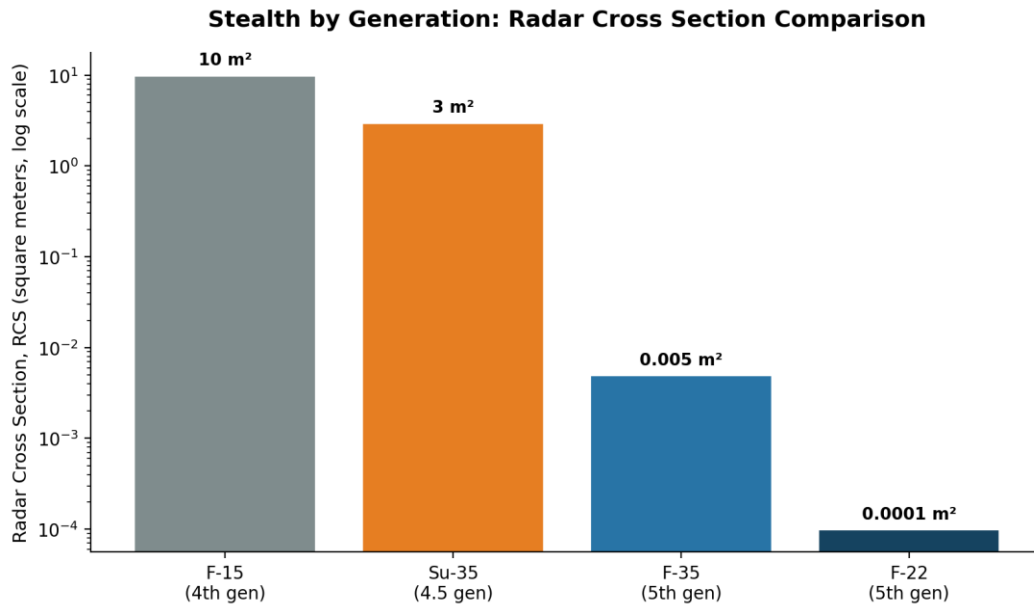


Chart: Approximate radar cross section (RCS) by fighter generation, log scale (author's diagram; figures are widely cited open-source estimates, not official values).

The fifth generation brought a revolution in the concepts of aerial combat: the first principle in combat is not being seen. Fifth-generation fighters are designed to penetrate deep into enemy defenses, strike key targets, and return without engagement. If forced to engage, thanks to stealth and advanced avionics, they fire before the enemy even notices their presence.

The Pillars of the Fifth Generation (Five Core Characteristics)

Inherent stealth: this is not merely coating an aircraft in black paint. Airframe design with precise angles, such as parallel edges on the F-22, reflects radar waves away from the transmitter. Internal weapons bays, no external pylons, S-shaped air intakes, to hide the engine compressor, and radar-absorbent material, RAM, coating. The radar cross section, RCS, of an F-22 is roughly 0.0001 square meters, the size of a marble, while an F-15's is roughly ten square meters. This means an enemy radar must be thousands of times more powerful to see an F-22 at the same range.

High-power AESA radar: the active electronically scanned array on the F-35, the AN/APG-81, can simultaneously track targets, jam electronically, and even hack enemy radars.

Supercruise: stable flight at Mach 1.5 to 1.8 without using the afterburner, which produces high heat and reveals the aircraft. The F-22 was the first fighter with this capability, with two F119-PW-100 engines. The F-35 lacks full supercruise but can briefly reach Mach 1.2.

Sensor fusion: a computer system combines radar data, own stealth status,IRST, radar warning, and data links from other aircraft, presenting a comprehensive three-dimensional picture to the pilot, or his helmet. The pilot no longer needs to switch between different displays.

Full network-centric capability: real-time exchange of information with ground command, AWACS aircraft, ships, and even accompanying drones. This feature reaches its peak in the F-35: every F-35 functions as an information-gathering node, sharing the battlefield picture with others.

Operational or Near-Operational Fifth-Generation Fighters

The F-22 Raptor, United States: the first and best fifth generation. 195 units built, production halted. With sky-high stealth, the best RCS in its class, Mach 1.8 supercruise, and AIM-120C missiles, six in the internal bay, and AIM-9X, two units. Primary mission: pure air superiority. Limitation: not especially long range. In the wars in Syria and Iraq, F-22s patrolled without even being seen by Syrian army radars.

The F-35 Lightning II, United States and partners: multi-role, in three versions, A, conventional, B, VTOL, vertical takeoff and landing, and C, carrier-based. Stealth at a level below the F-22 but with far more advanced avionics, the AN/APG-81 and the distributed aperture system, DAS, which lets the pilot see through the floor of the cockpit. Criticisms: no supercruise, moderate maneuverability, though with the HMDS helmet and the high-off-boresight AIM-9X missile, it is dangerous in close combat. More than one thousand units built, in service in Israel, Japan, South Korea, and Britain. Reportedly used, according to unofficial information, in Ukraine to intercept cruise missiles.

The Su-57 Felon, Russia: Russia's first fifth generation. With two AL-41F1 engines, Mach 1.6 supercruise, an internal bay for six missiles. The N036 Byelka AESA radar. Its stealth, owing to relatively large panel seams and gaps, does not match American levels, estimated RCS 0.1 to 0.5 square meters. As of early 2024, only twenty-two units produced. Used occasionally, but cautiously, in the war in Ukraine.

The J-20 Mighty Dragon, China: the largest fifth-generation fighter, roughly the size of the Su-27. Two engines, canards, possible, unconfirmed, supercruise. An internal bay for six long-range PL-15 missiles, range 200-plus kilometers. Chinese-made AESA radar. The J-20's main goal is intercepting and destroying enemy AWACS aircraft and tankers in the Pacific. More than two hundred units operational by 2024.

The J-31/FC-31, China: a smaller project, similar to the F-35 but twin-engine. Mainly for export and naval use. Not yet operational.

Fifth-Generation Tactics

In military exercises, such as Red Flag, the F-22 and F-35 have recorded kill ratios of more than twenty to one against the F-15 and F-16. Common tactic: jam and penetrate, fire a missile from fifty to eighty kilometers, even before the enemy's radar can lock on, then withdraw. Close combat with the fifth generation is rare, and if it occurs, thanks to the combined helmet and high-angle missiles, they almost always win.

Sixth Generation (2030 and Beyond: The Near Future)

The sixth generation has not yet flown, but every great power, the United States, China, Russia, Europe, Britain, has a serious program for it. The proposed features go far beyond the fifth generation, and some blur the line between manned and unmanned aircraft.

Main Expected Features

Multi-band, adaptive stealth: not only in the X-band, the band of combat radars, but in the VHF/UHF bands used by early-warning radars. Using camouflage plasma or smart surfaces that can change their radar signature in real time. Stealth against millimeter-wave and infrared radars is also being considered.

Directed-energy weapons: an airborne laser with a power of one hundred to three hundred kilowatts to destroy enemy missiles, drones, and even burn out the sensors of rival aircraft. Also high-power microwave, HPM, weapons to disrupt enemy electronics. The United States is testing lasers on the F-15 and on drones.

Hypersonic missiles, Mach 5 to 10, capable of maneuvering in the upper atmosphere. These missiles can be carried in an internal bay.

Control of accompanying drone swarms, loyal wingman: each sixth-generation fighter functions as a mothership for four to ten combat drones. These drones serve various roles: reconnaissance, jamming, missile attack, and even being sacrificed to reveal enemy positions. The pilot, instead of flying one aircraft, leads an aerial combat network. An experimental example: America's XQ-58A Valkyrie drone.

Adaptive-cycle engines: an engine that can switch between turbofan mode, for fuel efficiency on long journeys, and turbojet mode, for high power in combat. These engines also radiate less heat outward, reducing thermal tracking. Example: General Electric's XA100 engine.

Virtual cockpit and artificial intelligence: the pilot works with an augmented-reality, AR, helmet that not only projects sensor images onto the visor but also uses head and eye movement for weapon aiming. An artificial intelligence, sometimes called a virtual co-pilot, also executes many tactical decisions, such as choosing the best firing angle, activating jamming, or dispatching drones, automatically or semi-automatically.

A tailless airframe and extreme shapes: to further reduce RCS and drag, the sixth generation will likely have no vertical tail. Directional control will be handled by moving wing surfaces or three-dimensional thrust vectoring systems.

Main Programs Under Development

NGAD, Next Generation Air Dominance, United States: two separate programs for the air force and the navy. The air force seeks to replace the F-22 with a family of systems including a manned fighter and a group of drones. A prototype has flown, 2020, but details are classified.

F/A-XX, United States Navy: successor to the F/A-18E/F and part of the carrier air wing. Focused on long-range strikes and naval air superiority.

Tempest, Britain, Italy, Japan: a joint program, originally named Tempest, now the Global Combat Air Programme, with a first test flight planned for the mid-2030s. Main features: a cockpit free of some displays, control of cooperating drones, and quantum-processing radar.

FCAS, Future Combat Air System, France, Germany, Spain: led by Dassault and Airbus. A sixth-generation fighter alongside drones called Remote Carriers. Planned to replace the Rafale and Typhoon from 2040.

China and Russia: China is pursuing the J-XD/JH-XX program, likely a heavy, tailless fighter capable of carrying hypersonic missiles. Russia also has a concept called the MiG-41, a long-range supersonic interceptor claimed to be capable of flying in the upper atmosphere, near space, but owing to economic problems, is unlikely to reach production before 2040.

Closing Word: The Coexistence of Generations

Despite dazzling advances, fourth-generation and 4.5-generation fighters will remain in service for decades to come. The reason is simple: price. An F-35 costs roughly eighty to one hundred million dollars, and the B version more, while an upgraded F-16V costs roughly forty million dollars and is equally effective for most missions, bombing, close air support, patrolling in areas with weak air defenses. Training fifth-generation pilots is also time-consuming and expensive. As a result, even in the 2050s, we will see F-16s, Su-30s, and Mirage 2000s still flying in the skies of developing countries and even some middle powers.

But in any conflict between great powers, such as the United States and China, or NATO and Russia, the presence of fifth- and sixth-generation aircraft will be decisive. Future aerial battles are no longer a duel of young pilots with combat maneuvers; they are a battle of sensors, algorithms, stealth, and radar hacking. The pilot is only the one who, in the end, presses the firing button, but hundreds of processors have analyzed the scene before him.

Special Feature

The McDonnell Douglas F-4 Phantom II: The Cold War's Amphibious Workhorse

The Pivotal Moment: May 10, 1972, the Skies over Hanoi, North Vietnam

It was eleven in the morning. Major Rob Robinson and radar officer William Ritchie were flying their F-4E Phantom on an air patrol over a well-known industrial facility in Hanoi. Suddenly, the radar officer shouted, bandits, two o'clock, low altitude! Two Soviet-built Viet Cong MiG-21s were closing fast. Robinson pulled the trigger for his Sparrow missiles, AIM-7E. But the missile missed owing to range limitations. The MiGs had closed so near that the Sparrow was no longer effective. The only weapon that worked at this range, under a kilometer, was the heat-seeking

Sidewinder missile, AIM-9, and the twenty-millimeter cannon. Robinson pulled the trigger for the Sidewinder. The missile left its rail and streaked toward one of the MiGs. But the MiG pilot, with a violent turn, evaded it. William shouted, guns, it's our only chance! Robinson swung the Phantom into a deadly turn, incredible for a fifteen-ton aircraft, toward the MiG. He pulled the trigger for the twenty-millimeter cannon. A burst of rounds punched through the MiG's left wing. The MiG began to fall. The Viet Cong pilot bailed out with his parachute. Robinson later wrote in his memoirs that that day he understood the Phantom was not a flying brick, but a winged ox that, when angered, could dance.

Eyewitness testimony, from the margins of the Vietnam War, 1972, in the voice of an American pilot, rendered here in translation, recalls that they called the Phantom a flying brick, but that anyone who says the Phantom can't maneuver has never chased a MiG in a turn; that with two 17,000-pound engines, they sent fifteen tons of steel into the sky and, with that same brick, wove rings of death around the enemy; the Phantom was ugly, boxy, but never weak. From the memoirs of the American pilot John Chesney.

Design Philosophy and Historical Background

The F-4 Phantom II was designed in the late 1950s by the McDonnell company, later McDonnell Douglas, for the United States Navy. At that time, designers believed future aerial combat would no longer be close and direct, but conducted from a distance with radar-guided missiles. For this reason, the F-4 initially had no internal cannon at all, and was equipped only with AIM-7 Sparrow, semi-active radar, and AIM-9 Sidewinder, heat-seeking, missiles. The Phantom also required two crew members: a pilot and a weapons systems officer, WSO, responsible for radar, navigation, and missile management. The name Phantom II came from McDonnell's earlier fighter, the FH-1 Phantom.

The F-4's first flight took place in 1958, and it joined the United States Navy in 1961. Its success was such that air force pilots too strongly wanted it, and from 1963 the air force also fielded its own land-based versions, the F-4C, D, and E. The Marine Corps also used the F-4 as an attack and support fighter. The F-4 quickly became the primary weapon of NATO and America's allies in the Cold War, serving eleven countries, including Iran, West Germany, Japan, Israel, Britain, Egypt, and Australia. In total, more than 5,195 F-4 units were built across various versions.

Technical Specifications and Performance

The F-4 Phantom II is a two-seat, twin-engine fighter with a cranked delta wing and a drooping nose. Its length is 19.2 meters, wingspan 11.7 meters, and height five meters. Empty weight is roughly 13,750 kilograms, and its maximum takeoff weight reaches 28,000 kilograms, a figure that makes it one of the heaviest third-generation fighters. Its engines are two General Electric J79-GE-17 turbojets with an afterburner output of 79.6 kilonewtons. Its maximum speed is Mach 2.23, 2,370 kilometers per hour, and its service ceiling is 18,300 meters. Its operational range with external tanks reaches 2,600 kilometers. Its initial climb rate is 210 meters per second, remarkable for an aircraft of this weight.

The major design flaw, the absence of an internal cannon: early versions, the F-4B, C, D, had no cannon fitted. Designers believed missiles had replaced the cannon. But the Vietnam War showed that early missiles were unreliable, and pilots repeatedly found themselves at close range with MiGs without an effective close-range weapon. As a result, the F-4E version mounted a twenty-millimeter M61A1 Vulcan cannon with 639 rounds beneath the nose. Earlier models were later equipped with this capability via an external gun pod, the SUU-16/A.

Weapons and radar: the F-4 has nine external hardpoints for carrying up to 8,400 kilograms of ordnance. Its standard weapons include four AIM-7 Sparrow missiles, semi-active radar, range forty-five to eighty kilometers, four AIM-9 Sidewinder missiles, heat-seeking, range eighteen to thirty-five kilometers, anti-tank rockets, and conventional bombs, up to nine hundred kilograms. The air force version could also carry the B43, B57, and B61 tactical nuclear bombs. Its main radar is the AN/APQ-120, range ninety kilometers, for searching and tracking aerial targets. Earlier versions carried the AN/APQ-72 radar.

Operational History and Major Battles

The Vietnam War, 1965 to 1973: the Phantom's largest and most challenging battlefield. F-4s operated as interceptors, in ground attack, close support, and reconnaissance photography. Official American statistics show that air force and navy F-4s achieved 195 aerial victories against Viet Cong MiGs, mostly MiG-17s and MiG-21s, but in return, 528 F-

4s were lost for various reasons, including anti-aircraft fire, surface-to-air missiles, and crashes. The kill ratio to losses was roughly 2.8 to one, far lower than the thirteen-to-one ratio of the Korean War, F-86 against MiG-15. The main reason was the prohibition on cross-border fire, firing at unidentified targets, and cumbersome rules of engagement, not weakness in the Phantom. The F-4 was the first and only aircraft both to down a MiG and be downed by a MiG in the same battle. Also, one Phantom pilot, Major Richard Ritchie, with five aerial victories, became an ace.

The Yom Kippur War, 1973: the Israeli air force, with the F-4E Phantom, which they called the Kurnass, sledgehammer, fought against Egyptian and Syrian aircraft, MiG-21, Su-7, MiG-17. Israel too took losses, but the Phantoms played a key role in destroying air defenses and tanks.

The Iran-Iraq War, 1980 to 1988: Iran's air force, the IIAF and later the IRIAF, with 225 F-4D and F-4E units, delivered in the 1970s, held one of the largest Phantom arsenals in the world. Iranian Phantoms performed well in aerial battles against Iraqi MiG-21s, MiG-23s, MiG-25s, Su-20s, and Su-22s, and Iranian pilots, using bold maneuvers and the power of the twenty-millimeter cannon, recorded several aerial victories. Phantoms also took part in strategic bombing and close support, including the strike on the H-3 air base deep inside Iraqi territory, considered one of the boldest air operations in history.

Strengths and Weaknesses

Strengths: very high ordnance capacity, 8.4 tons, more than many Second World War bombers; very high speed, Mach 2.2, and excellent climb power; a radar and long-range missile system, for its time; two engines, providing greater safety if one is damaged; and extraordinary tactical flexibility, from interceptor to bomber to reconnaissance.

Weaknesses: the absence of an internal cannon in early versions, later corrected; thick black smoke from the J79 engines, which made the Phantom visible from a distance, in Vietnam, the Phantom's black smoke could be seen from twenty kilometers, warning MiG pilots; weaker maneuverability compared to the MiG-21, though still acceptable with correct tactics; high fuel consumption and limited range on heavily loaded missions; and maintenance complexity, two engines and a complex hydraulic system.

Legacy and Retirement

The F-4 Phantom II, over four decades of active service in more than fifteen countries, took part in eight major wars. The United States Navy eventually retired its last F-4s in 1986. The United States Air Force bid farewell to the F-4E in 1996. Even so, some countries, such as Iran, Greece, Turkey, Egypt, and South Korea, used this aircraft into the mid-2000s and even today, Iran and Turkey still had a limited number of operational F-4s as of 2026. The Phantom symbolizes the transition from the age of the cannon and machine gun to the age of the missile and radar; though this transition was not without trouble, the F-4 taught a new generation of pilots that missiles had not replaced individual skill, but complemented it. The Phantom's legacy is clearly visible in the design of the F-15, the F-14, and even the F-18. The brick-like Phantom, which learned to fly by brute engine force, ultimately became one of the most beloved fighters in history.

Special Feature

The Northrop F-5 Freedom Fighter/Tiger II: The Agile, Cheap Pony of the Cold War

The Pivotal Moment: June 19, 1982, the Bekaa Valley, Lebanon

It was two in the afternoon. The Israeli pilot Yoel was flying his F-5E Tiger II at three thousand meters on patrol over the Bekaa Valley. Suddenly, an unknown target approached fast from the east. The F-5's small radar classified the target as a Syrian air force MiG-23 Flogger. The MiG-23 was superior to the F-5 in every respect: faster, with a stronger radar and longer-range missiles. But Yoel knew the F-5's advantage lay in its agility and small size. The MiG fired at him. An R-23 missile, AA-7 Apex, left the MiG's wing. Yoel, with a violent nine-g turn, evaded the missile. He then dove toward the MiG. The F-5's low speed let him achieve a smaller turning radius. At five hundred meters, he brought the target into his sight. Two AIM-9L Sidewinder heat-seeking missiles, capable of firing from any angle, left the F-5's wings. The first missile struck the MiG's hot engine exhaust and turned the aircraft into a fireball. The Syrian pilot bailed out with his parachute. Yoel flew past the scene and returned to base. This was his third aerial victory with the F-5 that same month. After the war, Yoel said in an interview that the MiGs were faster, with stronger radars, but that in close combat, the F-5 was king, small, agile, and lethal; they called it the war pony, but even a pony, when angered, can bite a lion.

Eyewitness testimony, from the margins of the Battle of the Bekaa Valley, 1982, in the voice of an Israeli pilot, rendered here in translation, recalls flying their F-5s at low altitude; the Syrians calling them paper hawks; but those same paper hawks downing thirty of their advanced MiGs in one week; not with strong radar, not with long-range missiles, but with agility and daring; the F-5 taught you that size doesn't matter, what matters is who pulls the trigger first in close combat. From the memoirs of the Israeli pilot Yossi Langotsky.

Design Philosophy: The People's Fighter Against the Aristocrat's Fighter

In the early 1950s, the United States Air Force concluded that, to assist its allies, especially developing countries that could not afford the F-104 and F-4, it needed a light, simple, cheap, and easily maintained fighter. The result was the Fighter for Assisted Nations project, which later became the T-38 Talon trainer and the F-5 Freedom Fighter. The F-5's design philosophy rested on three simple principles: small and agile for superiority in close combat; two small, fuel-efficient engines to increase reliability and reduce the risk of losing both engines to damage; and low production and maintenance cost, less than a quarter of the F-4 Phantom's. Unlike the F-4, which was an aristocratic and expensive fighter, the F-5 became known as the people's fighter. Indeed, from the outset, the F-5 was designed with the view that a good fighter need not necessarily be large and expensive.

The F-5A's first flight took place in 1959, and it entered United States Air Force service in 1962. But the American air force never used the F-5 as a front-line fighter, purchasing only a few hundred units for tactical training and aggressor roles. Instead, the F-5 was mainly exported to dozens of allied countries and gained fame in the wars in Vietnam, the Arab-Israeli conflicts, Iran and Iraq, and India and Pakistan. Its advanced version, the F-5E Tiger II, was introduced in 1972 with a larger airframe, more powerful engines, and a more advanced radar, the AN/APQ-159. In total, more than 2,600 F-5 units were built across various versions, A, B, E, F, as well as a Chinese export version, the J-5.

Technical Specifications and Performance

The F-5 is a single-seat, versions A and E, or two-seat, versions B and F, twin-engine fighter with a forty-five-degree delta wing and a sharp nose. Its length is 14.4 meters, version E, wingspan 8.1 meters, and height 4.1 meters. Empty weight is roughly 4,350 kilograms, version E, and its maximum takeoff weight reaches 11,187 kilograms, one of the lightest third-generation fighters. Its engines are two General Electric J85-GE-21 turbojets with an afterburner output of 22.2 kilonewtons each. Its maximum speed is Mach 1.64, 1,740 kilometers per hour, and its service ceiling is 15,700 meters. Its operational range, unrefueled, is roughly 1,400 kilometers, extending to 2,500 kilometers with external tanks. Its initial climb rate is 175 meters per second.

The secret of the F-5's agility: its delta-wing design, a very small turning radius, only 360 meters at Mach 0.6, and a high thrust-to-weight ratio, roughly 0.86 in a light combat configuration, allowed the F-5 to outmaneuver far larger and faster aircraft in close combat, the dogfight. Soviet pilots in Vietnam nicknamed the F-5 the wild hornet, since, like a small hornet, it was very dangerous.

Weapons and radar: the F-5 has seven external hardpoints, five under the fuselage and wings, two at the wingtips, with a maximum ordnance capacity of 3,200 kilograms. Its standard weapons include two twenty-millimeter M39 Pontiac cannon, in the nose, 280 rounds each, two AIM-9 Sidewinder heat-seeking missiles, on the wingtips, seventy-millimeter rockets, and conventional bombs up to nine hundred kilograms. The F-5E Tiger II version was equipped with the AN/APQ-159 radar, range seventy kilometers, capable of tracking eight targets and firing on two. The F-5 could not carry radar-guided missiles, such as the AIM-7 Sparrow, and this was one of its main weaknesses against aircraft equipped for BVR, beyond visual range, combat.

Operational History and Major Battles

The Vietnam War, 1965 to 1973: the United States Air Force never sent the F-5 to Vietnam for combat missions. Even so, F-5s of the South Vietnamese air force, VNAF, were used in close support and light bombing roles. After the fall of Saigon in 1975, dozens of F-5s fell as spoils to North Vietnam and were later handed over to the Soviet Union and Poland.

The Yom Kippur War, 1973, and the Battle of the Bekaa Valley, 1982: the Israeli air force, IAF, was the largest and most successful user of the F-5 in the world. Israel fielded 121 F-5A and F-5E units under the name Kfir, replacing the original engines with more powerful J79 engines, which later became the independent Kfir fighter, while also retaining a number of original F-5s. In the Yom Kippur War, F-5s performed successfully in close aerial combat against Egyptian and Syrian MiGs, MiG-17, MiG-21, recording roughly fifteen aerial victories. In the Battle of the Bekaa Valley, 1982, F-5s, now retired and replaced by Kfirs, played a secondary role but still downed several MiG-23s.

The Iran-Iraq War, 1980 to 1988: in the 1970s, Iran purchased only fourteen F-5A units, and a number of two-seat F-5B units, from the United States. During the war, Iranian F-5s were used in close support and light bombing, with 250-kilogram bombs, roles and recorded several, rare, aerial victories against Iraqi MiG-21s and Su-20s. Even so, owing to their small number and the lack of spare parts after the revolution, the F-5's role in Iran was limited.

The India-Pakistan wars, 1971 and 1999: India did not field the F-5, but Pakistan received thirty F-5A and F-5B units through the American military aid program and used them successfully against Indian aircraft, Su-7, Hawker Hunter, in the 1971 war, recording several aerial victories.

The F-5 as an Aggressor: Training American Pilots

Although the United States never fielded the F-5 as a front-line fighter, in the 1970s the American air force thought to use the F-5 to train its own pilots, who flew the F-15 and F-16, against Soviet tactics. The reason: the F-5, in size and agility, closely resembled the MiG-21 and MiG-23. The air force formed Aggressor Squadrons with the F-5. Pilots of these squadrons trained F-15 and F-16 pilots in aerial maneuvers. Indeed, the F-5 was so successful in this role that, until 2022, when America's last F-5s were retired, it was still used in the air force's tactical schools. F-15 pilots joked that if you see an F-5 in the sky, run, because its pilot is not an ordinary pilot, but a trained killer who will teach you every mistake you make.

Strengths and Weaknesses

Strengths: extraordinary agility and a very small turning radius, an absolute advantage in close combat; very low purchase and maintenance cost, roughly a quarter of the F-4's; two engines, increasing reliability and safety; simplicity of design and standard parts, easing repair and maintenance; and a simple but adequate radar for close-support missions and limited interception.

Weaknesses: the inability to carry long-range radar-guided missiles, only heat-seeking missiles; low speed, Mach 1.6, compared to contemporary rivals, the MiG-21 at Mach 2.0 and the MiG-23 at Mach 2.3; the inability to carry heavy

ordnance, a maximum of 3.2 tons against 8.4 tons for the F-4; a weak, short-range radar, seventy kilometers against ninety-plus kilometers for the F-4 and MiG-23; and the absence of aerial refueling capability in early versions, later added to advanced versions.

Legacy and Retirement

The F-5 Freedom Fighter/Tiger II, with more than 2,600 units built and service in more than thirty countries, is one of the most successful light and export fighters in history. This aircraft, known as the wild hornet fighter and the war pony, proved that air superiority does not necessarily require long-range missiles and complex radars; sometimes agility, simplicity, and pilot skill are enough. The United States Air Force retired its last F-5s in 2022, but countries such as Brazil, Morocco, Indonesia, Thailand, and Kenya still use upgraded versions, with new radar, glass cockpits, and the capability to carry modern Python-4 missiles. The F-5 left its legacy in the next generation of trainer aircraft, such as the T-38 Talon, and modern light fighters, such as the FA-50 Golden Eagle. The F-5 was the agile pony that brought giants to the ground in close combat.

Special Feature

The Grumman F-14 Tomcat: Knight of the Sky with Swing Wings

The Pivotal Moment: August 19, 1981, the Gulf of Sidra, the Mediterranean Sea

It was seven in the morning. Two F-14 Tomcats had launched from the aircraft carrier USS Nimitz and were on air patrol over the Gulf of Sidra. Libya had declared this area its territorial waters, a claim the United States did not recognize. Suddenly, the Tomcat's AN/AWG-9 radar detected two Libyan air force Su-22 Fitters approaching from Sidi Bilal air base. The American pilot, Lieutenant Henry Kleemann, confident in his powerful radar, prepared his AIM-54 Phoenix missiles to fire. But the navy commander had ordered that the enemy first be warned by radio. Suddenly, one of the Su-22s fired an AA-2 Atoll heat-seeking missile at the Tomcat. Kleemann, with a violent seven-turn, evaded the missile. He then ordered his radar officer, Lieutenant Larry Muczynski, lock radar, fire the Phoenix! But the Phoenix was not designed for this close range, under fifteen kilometers. Muczynski shouted, Sidewinder! Kleemann released an AIM-9L Sidewinder, heat-seeking, missile from the Tomcat's wing. The missile struck the Su-22's hot engine exhaust and set the aircraft ablaze. The Libyan pilot bailed out with his parachute. The second Su-22 also tried to flee but was downed by another Tomcat, piloted by Lance Smith, with a Sidewinder missile. This aerial battle, later known as the Gulf of Sidra incident, was the F-14 Tomcat's first aerial victory in history. American destroyers pulled the burned wreckage of the Su-22 from the water and displayed it as a trophy at the Navy museum.

Eyewitness testimony, from the margins of the Gulf of Sidra incident, 1981, in the voice of the American pilot Henry Kleemann, rendered here in translation, recalls the Su-22 appearing as a major threat on the radar screen; telling the radar officer, get ready, it's time to fire; but him shouting, Sidewinder, Sidewinder! At that moment, being so close to the enemy that the Tomcat's wings nearly crossed the Su-22's; pulling the trigger; the cockpit engulfed in fire; looking down, the Libyan pilot floating in the Mediterranean under his parachute; that day, for the first time, feeling the F-14 was not just an aircraft, but a predator.

Design Philosophy: A Long-Range Carrier Interceptor with the Phoenix Missile

In the late 1960s, the United States Navy realized that its current fighters, such as the F-4 Phantom II, could not counter a new threat posed by the Soviet Union: long-range Tu-22M Backfire bombers that could fire anti-ship cruise missiles, such as the AS-4 Kitchen, at aircraft carriers from a great distance. The navy needed a fleet air defense fighter equipped with a radar with a range beyond two hundred kilometers and long-range missiles that could destroy bombers and cruise missiles from a hundred kilometers before they reached the carrier. The result was a competition between Grumman and McDonnell Douglas, which Grumman ultimately won in 1969 with its Model 303 project, named the F-14 Tomcat. The name Tomcat was chosen in honor of Admiral Thomas Connolly, nicknamed Tom, who played a role in developing carrier-based aircraft, and also referenced the wild male cat breed. The F-14's first flight took place in 1970, and it entered United States Navy service in 1974.

Swing wing: one of the F-14's unique features is its variable-sweep wing. The pilot could adjust the wing angle from twenty degrees, for takeoff, landing, and economical patrol, to sixty-eight degrees, for supersonic flight and reduced drag. In storage position, the wings could also fold to seventy-five degrees so the aircraft would occupy less space on the carrier deck. This aerodynamic design allowed the F-14 to perform excellently both at low speed, maneuvering aboard the carrier, and at high speed, chasing bombers.

Technical Specifications and Performance

The F-14 Tomcat is a two-seat, pilot and radar officer, twin-engine fighter with a variable-sweep wing and two large vertical tails. Its length is 19.1 meters, wingspan when spread, twenty degrees, 19.55 meters, and when swept, sixty-eight degrees, 11.6 meters. Its height is 4.9 meters. Empty weight is roughly 19,800 kilograms, and its maximum takeoff weight reaches 33,700 kilograms, one of the heaviest third- and fourth-generation fighters. Its engines are two Pratt & Whitney TF30-P-414A turbofans with an afterburner output of ninety-three kilonewtons each. Later, in the F-14A Plus and F-14D versions, more powerful General Electric F110-GE-400 engines with an afterburner output of 123 kilonewtons were installed. Its maximum speed is Mach 2.34, 2,485 kilometers per hour, and its service ceiling is 15,240 meters. Its operational range with external tanks is 2,960 kilometers, and its ferry range is 3,400 kilometers. Its initial climb rate is 230 meters per second.

Radar and the Phoenix missile, the beating heart of the Tomcat: the AN/AWG-9 radar, later the AN/APG-71, was one of the most advanced radars of its time. Its range against bomber-sized targets, large RCS, reached three hundred kilometers, and against fighter-sized targets, small RCS, up to 215 kilometers. The AWG-9 radar could track twenty-four targets and fire simultaneously on six. The AIM-54 Phoenix missile, built specifically for the F-14, with a range of 180 kilometers and semi-active radar guidance in the midcourse phase and active guidance in the terminal phase, fire-and-forget capability, could destroy enemy bombers before they reached aircraft carriers. Each F-14 could carry four to six Phoenix missiles, depending on version. The cost of each Phoenix missile in the 1980s reached six hundred thousand dollars, and the F-14 became known as the missile arm of the aircraft carrier.

Weapons and External Hardpoints

The F-14 Tomcat has ten external hardpoints, four under the fuselage, six under the wings and fuselage, with a maximum ordnance capacity of 6,577 kilograms. Its standard weapons include one twenty-millimeter M61A1 Vulcan cannon on the left side of the nose, 675 rounds, up to six AIM-54 Phoenix missiles, long-range radar, 180-kilometer range, up to four AIM-7 Sparrow missiles, semi-active radar, forty-five to eighty-kilometer range, and up to four AIM-9 Sidewinder missiles, heat-seeking, eighteen to thirty-five-kilometer range. It can also carry conventional bombs, up to nine hundred kilograms, and rockets. The F-14 could also carry the B43, B57, and B61 tactical nuclear bombs.

Operational History and Major Battles

Its role in the film *Top Gun*, 1986: the F-14 Tomcat's global fame owes much to the film *Top Gun*, starring Tom Cruise. This film, which told the story of pilots at the navy's tactical school, TOPGUN, made the F-14 a symbol of American military aviation. In the film, Tom Cruise, flying the F-14, depicted breathtaking aerial battles against mock MiGs, actually played by F-5s. After the film's release, thousands of young Americans enlisted to join the navy.

The Iran-Iraq War, 1980 to 1988, the Tomcat's lost paradise: before the 1979 Islamic Revolution, Iran's Imperial Air Force, IIAF, ordered seventy-nine F-14A units and 284 AIM-54 Phoenix missiles, and took delivery of seventy-nine units and 284 missiles into service. After the revolution, Iran faced sanctions on parts and munitions, but through reverse engineering and parts repair, kept a number of F-14s operational. During the Iran-Iraq War, Iranian Tomcats recorded at least thirty to fifty aerial victories, depending on the source, against Iraqi aircraft, MiG-21, MiG-23, MiG-25, Su-20, and Su-22. Iranian pilots, using AIM-54 Phoenix and AIM-7 Sparrow missiles, could target Iraqi aircraft from a great distance, fifty to one hundred kilometers. In numerous cases, with bold maneuvers, they also succeeded in downing Iraqi MiGs with the twenty-millimeter cannon. Captured Iraqi Tomcats, those struck in combat operations, were later displayed in Saddam's museums. The Iranian pilot known as Major Shapour, a member of Iran's *Top Gun* team, with eleven aerial victories, all with the F-14, is recognized as one of the most successful Tomcat pilots in the world.

American navy service, 1974 to 2006: American F-14s never took part in direct engagement with Soviet aircraft, since no war occurred, and recorded only a few limited aerial victories against Libyan aircraft, two Su-22s in 1981 and two MiG-23s in 1989, and later in Iraq, 1991. In Operation Desert Storm, 1991, F-14s mostly served in air patrol and bomber escort roles and downed several Iraqi helicopters. In the Iraq and Afghanistan wars, 2003 to 2006, F-14s were also used in precision bombing roles, with JDAM bombs, demonstrating their multi-role capability.

Strengths and Weaknesses

Strengths: the AN/AWG-9 radar, later the APG-71, with extraordinary range, up to three hundred kilometers; the AIM-54 Phoenix missile, with a range of 180 kilometers and the ability to engage several targets simultaneously; the variable-sweep wing, which provided a balance between low-speed maneuverability and high-speed performance; the ability to carry heavy ordnance, 6.5 tons, and a diverse weapons mix, from long-range missiles to guided bombs; and a large, sturdy airframe capable of absorbing significant damage.

Weaknesses: very high operating and maintenance cost, one of the most expensive fighters in history; inefficient, unreliable early TF30 engines, in the early years, many F-14 crashes were due to engine failure; complex aerodynamics and a variable-sweep-wing system requiring specialized maintenance; the absence of single-engine flight capability, if one engine failed, the F-14 usually crashed; and very high weight, 33.7 tons at maximum takeoff weight, which reduced maneuverability compared to light fighters such as the F-16.

Legacy and Retirement

The F-14 Tomcat was officially retired from United States Navy service on September 22, 2006. The main reason for retirement was heavy maintenance costs, combined with the absence of the Soviet bomber threat after the Soviet Union's collapse, and the emergence of more multi-role, modern fighters such as the F/A-18 Super Hornet. The Tomcat's last operational flight took place in April 2006. At the retirement ceremony, the commander of the United States Navy said that they no longer needed a forty-ton, long-range interceptor with a 180-kilometer Phoenix missile, that the age of the Tomcat had ended. Even so, Iran's air force, the IRIAF, as of 2026 still had roughly thirty to forty F-14A units in service, and through reverse engineering and domestic overhaul, has kept them operational. Iran has also succeeded in building the Fakour missile, similar to the AIM-54 Phoenix, and the Sedjil, similar to the AIM-7 Sparrow, to arm its Tomcats. Iranian Tomcats still take part in annual exercises and serve as a pillar of Iran's air deterrence.

The F-14 Tomcat, with its swing wings, symbolized an era of military aviation in which aircraft were designed for one specialized role, the long-range interceptor, and required fundamental modification to perform other missions, close bombing, ground support. The Tomcat was the wild cat of the sky, its claws armed with the Phoenix missile, but in the end its roar fell silent in museums and survived only in Iran's skies. For the pilots who flew it, the F-14 was not an ordinary aircraft, but an iron mistress.

Special Feature

The McDonnell Douglas F-15 Eagle: The Unmatched Bird of Prey of the Sky

The Pivotal Moment: February 6, 1991, the Skies over Iraq, Operation Desert Storm

It was four in the morning. Captain Tony Murphy and radar officer Tom Griffith, in their F-15E Strike Eagle, were escorting a squadron of F-111s and stealthy F-117s. Suddenly, their AN/APG-70 radar detected two unknown targets sixty kilometers away at low altitude. The targets' signatures matched Iraqi air force MiG-29 Fulcrums. Confident in the F-15's superiority, Captain Murphy decided to intercept. At forty kilometers, he fired two AIM-120 AMRAAM missiles, range eighty kilometers. The first struck its target, but the second missed. The second MiG turned sharply toward Murphy and fired an R-73 missile, AA-11 Archer. Murphy, with a nine-g turn, evaded it. Tom Griffith then shouted, Sidewinder! Murphy fired an AIM-9L missile. The heat-seeking missile struck the MiG's engine exhaust and set the aircraft ablaze. The Iraqi pilot bailed out with his parachute before the explosion. After the battle, Murphy said in an interview that the F-15 was not just an aircraft, but a killing platform, that when you lock the enemy on radar,

you know he's doomed, that the Iraqi pilots never even got the chance to see them. In total, in Operation Desert Storm, American F-15s recorded at least thirty-six aerial victories with no losses whatsoever. No American F-15 was ever shot down in aerial combat.

Eyewitness testimony, from the margins of Operation Desert Storm, 1991, in the voice of a captured Iraqi pilot, rendered here in translation, recalls being in a MiG-29; suddenly the radar warning sounding; looking around, seeing nothing; a few seconds later, an explosion; his wingman's left wing separating; trying to flee, but another explosion; when the parachute opened, looking down; an F-15 passing overhead; never seeing where it came from; only one memory: two white smoke trails in the sky; that day understanding the F-15 was the merciless hawk of the sky.

Design Philosophy: Not a Pound for Air-to-Ground

In the late 1960s, the United States Air Force was dissatisfied with the F-4 Phantom's performance in the Vietnam War. Though the F-4 was a good fighter, it struggled in close combat, dogfights, against small, agile Viet Cong MiGs. The main reasons were high weight, thick engine smoke, and the absence of an internal cannon in early versions. The air force needed a pure air superiority fighter, unmatched in close combat, capable of defeating any Soviet aircraft, from the MiG-21 to the MiG-25, in any condition. The official air force requirement, F-X, included strict requirements: a thrust-to-weight ratio above one, excellent low-speed maneuverability, a powerful long-range radar, and a maximum speed of Mach 2.5. In 1969, McDonnell Douglas, maker of the F-4, won the competition and began the project under the name Model 199. The F-15's first flight took place in 1972, and it entered United States Air Force service in 1976. The F-15's advertising slogan of that era was: not a pound for air-to-ground. The F-15 Eagle was so successful that, to this day, 2026, more than 1,600 units have been built and it serves in seven countries: the United States, Israel, Saudi Arabia, Japan, South Korea, Qatar, and Singapore.

A thrust-to-weight ratio above one: one of the F-15's most important secrets of superiority over every contemporary rival was a thrust-to-weight ratio, the ratio of engine thrust to aircraft weight, above one, 1.07 in a light configuration. This meant the F-15's engines could carry the aircraft's weight upward without any help from the wings. In practice, this meant the F-15 could, under afterburner, climb vertically straight up, a capability only the F-15 and later some fourth-generation fighters, such as the Su-27, possessed. In aerial combat, this feature allowed a pilot to quickly climb from low altitude to a superior altitude and dive on the enemy from there.

Technical Specifications and Performance

The F-15 Eagle is a single-seat, versions A, C, twin-engine fighter with trapezoidal wings and two angled vertical tails. Its length is 19.4 meters, wingspan 13.1 meters, and height 5.6 meters. Empty weight is roughly 12,700 kilograms, and its maximum takeoff weight reaches 30,800 kilograms. Its engines are two Pratt & Whitney F100-PW-220 turbofans, F100-PW-100 in early versions, with an afterburner output of 105.7 kilonewtons each. Its maximum speed is Mach 2.5, 2,660 kilometers per hour, and its service ceiling is twenty thousand meters. Its operational range with external tanks is 4,600 kilometers, and its initial climb rate is 250 meters per second. The F-15 is one of the fastest fourth-generation fighters; only the Soviet MiG-25 and MiG-31 were faster.

The AN/APG-63 radar, early versions, the APG-70, later versions, and the APG-82, modern versions: the F-15's radar was, in its time, one of the most powerful fighter radars in the world. The AN/APG-63's range against fighter-sized targets, small RCS, reached 165 kilometers, and against bombers, large RCS, three hundred kilometers. The APG-70 radar, installed in the C and E versions, could track twenty targets and fire on eight. The newest version, the AN/APG-82(V)1, installed in upgraded F-15E versions, is an AESA, phased-array, radar with a range beyond 350 kilometers and advanced electronic-warfare capability.

Supercruise: contrary to popular belief, the F-15 does not have supercruise capability, sustained supersonic flight without afterburner, and needs the afterburner to reach Mach 1.5. This capability appeared in the F-22 Raptor and some other fighters. Maneuverability: although the F-15 is a large, heavy fighter, roughly twice the weight of the F-16, its special aerodynamic design and high thrust-to-weight ratio give it extraordinary maneuverability. F-16 pilots, the lightest, joke in exercises that the F-15 is like an elephant that dances but forgets its own weight.

Weapons and External Hardpoints

The F-15 Eagle has eleven external hardpoints, under the fuselage and wings, with a maximum ordnance capacity of 10,400 kilograms, more than Second World War bombers. Its standard weapons include one twenty-millimeter M61A1 Vulcan cannon, on the right wing, 940 rounds, up to four AIM-7 Sparrow missiles, radar-guided, up to four AIM-9 Sidewinder missiles, heat-seeking, up to eight AIM-120 AMRAAM missiles, active radar, in modern versions, and conventional bombs, up to nine hundred kilograms, and JDAM guided bombs. The F-15 can also carry B61 tactical nuclear bombs. The two-seat F-15E Strike Eagle version, designed specifically for precision ground attack, can carry up to 24,000 pounds, 10,886 kilograms, of ordnance and is equipped with aerial refueling capability and large external tanks.

Operational History and Major Battles

The Arab-Israeli wars, late 1970s to 1980s: the Israeli air force, IAF, was one of the first and most successful users of the F-15. Israel took delivery of fifty F-15A and B units, the Baz, in the late 1970s and deployed them in Arab wars against Syria and Lebanon. In the Battle of the Bekaa Valley, 1982, Israeli F-15s recorded thirty-four aerial victories, with no losses, against Syrian MiG-21s, MiG-23s, and MiG-25s. The Israeli pilot Moshe Melnik, with five aerial victories, all with the F-15, became an ace.

The Gulf War, 1991: the F-15's greatest battlefield triumph. In Operation Desert Storm, American and Saudi F-15s recorded at least thirty-six aerial victories, with no losses, against Iraqi aircraft. Iraqi pilots flying MiG-29s and MiG-25s were completely helpless against the F-15. The F-15's kill-to-loss ratio in this war was infinite, meaning no American F-15 crashed in aerial combat. The F-15E Strike Eagle, in a precision bombing role, also destroyed hundreds of Iraqi tanks and artillery pieces.

The Yugoslav wars, 1999, and Iraq, 2003 to 2011: F-15s were deployed in air patrol and precision bombing roles, with JDAM bombs, against Serbia and Iraq. In Iraq, the F-15E Strike Eagle, as a precision bomber, destroyed hundreds of targets. No aerial engagement with enemy fighters occurred.

The F-15 against the Su-27, exercises: F-15 pilots and Indian, with the Su-27, and Russian, with the Su-27 and Su-30, pilots have faced each other in joint exercises, Red Flag, Cope India. The results of these exercises are classified, but Western pilots believe the F-15 holds a slight edge over the Su-27 in close combat, owing to a higher thrust-to-weight ratio and better radar, while the Su-27 is superior at high angles of attack.

The Main F-15 Versions

The F-15A/B, single- and two-seat, air superiority: early versions, produced 1972 to 1979.

The F-15C/D, upgraded: the main versions in service, still serving with the United States and other countries. Equipped with the APG-63 radar and improved engines.

The F-15E Strike Eagle, two-seat, attack: the most famous version. Reinforced wings, a rear seat for the weapons systems officer, WSO, the ability to carry heavy ordnance, 10.8 tons, and external fuel tanks. In service with the United States, Israel, Saudi Arabia, South Korea, and Qatar.

The F-15EX Eagle II, newest generation: the latest version, entering service since 2021. Equipped with the AN/APG-82(V)1 AESA radar, an all-glass, fully digital cockpit, the capability to carry twelve AMRAAM missiles, more than any other fighter, and new F110-GE-129 engines. The United States Air Force plans to field roughly 144 F-15EX units by 2030.

Strengths and Weaknesses

Strengths: a very high thrust-to-weight ratio, above 1.07, and vertical-climb power; a powerful, long-range radar, up to three hundred kilometers in modern AESA versions; very high ordnance capacity, 10.4 tons, more even than the B-17 bomber; high speed, Mach 2.5, and extraordinary operational range, 4,600 kilometers; a brilliant combat record, with more than 110 aerial victories and no defeats in aerial combat, as of 2026; and high compatibility with modern upgrades, the EX version with AESA radar and a glass cockpit.

Weaknesses: large size and high weight, compared to the F-16; high operating cost, thirty thousand dollars per flight hour compared to twenty-five thousand for the F-16; the absence of stealth, RCS above ten square meters against radar, unlike the F-22 and F-35; the inability to supercruise, supersonic flight without afterburner; and, in close combat with agile 4.5-generation fighters such as the Su-30 and MiG-29, no absolute superiority.

Legacy and Future

The F-15 Eagle, despite its advanced age, more than fifty years since its first flight, remains at the front line of American and allied airpower. The main reason is the F-15EX's much lower cost compared to the F-35 and F-22, roughly eighty million dollars against 110 million for the F-35A, and its greater ordnance capacity, twelve AMRAAM missiles against four on the F-35. It is planned for the F-15 to remain in service into the 2040s and even the 2050s. The United States Air Force intends, by purchasing 144 F-15EX units, to replace its aging fleet, roughly 250 F-15C/D units. The F-15EX will serve as a missile truck alongside the stealthy F-22 and the multi-role F-35, providing mass firepower on the battlefield. Experts say the F-15 is the oldest eagle still hunting; it has no stealth, it is not radar-evading, but its talons are still sharp and its claws still lethal. With its AIM-120 missiles and new AESA radar, the F-15 can still destroy an enemy from eighty kilometers away, and that is exactly what matters in future wars.

Special Feature

The General Dynamics F-16 Fighting Falcon: The Unrivaled Fighter of the Masses

The Pivotal Moment: April 28, 1981, Osirak, Iraq

It was four in the afternoon. Eight Israeli air force F-16s were flying at an altitude of just thirty meters above the ground, over the Arabian desert. Their mission was secret and extremely dangerous: destroying the Osirak nuclear reactor near Baghdad. To avoid detection by Iraqi radar, the pilots had to fly at very low altitude and high speed. At any moment they might strike a rock formation or an oil derrick. Suddenly, the radar officer in the rear cockpit shouted to pilot Ze'ev Raz, enemy radar, band nine, has locked onto us! Raz ordered, prepare to release bombs, thirty seconds to target! At twenty kilometers from the reactor, the eight F-16s suddenly climbed from thirty meters to three thousand meters and released their heavy nine-hundred-kilogram MK-84 bombs. The bombs were fitted with retarding parachute fins to remain stable at high speed. Six bombs, with ten-meter accuracy, struck the reactor's main building and destroyed it. The F-16s then, executing evasive maneuvers, returned to Israel at Mach 1.2. No Iraqi aircraft managed to intercept them. This operation, known as Operation Opera, demonstrated the F-16's unmatched capability for precise, surprise strikes.

Eyewitness testimony, from the margins of Operation Opera, 1981, in the voice of the Israeli pilot Ze'ev Raz, rendered here in translation, recalls flying the F-16 at thirty meters; desert dust settling on the cockpit glass; telling the radar officer, count to twenty, then climb; him counting, five, ten, fifteen; shouting, climb! Pushing the throttle forward; the F-16 climbing toward the sky like a missile; releasing the bombs; on the rear radar, seeing the image of the reactor sinking into a cloud of fire and smoke; the F-16 was small, but it had the heart of a lion.

Design Philosophy: A People's Fighter Against an Aristocrat's Fighter

In the early 1970s, a group of young United States Air Force engineers, known as the Fighter Mafia, was deeply dissatisfied with the direction new fighter design, such as the F-15 Eagle, was taking. They believed the F-15 was an aristocrat's fighter: very expensive, heavy, complex, and not optimized for close combat, dogfighting. They sought a people's fighter: light, simple, cheap, and with extraordinary agility in close combat. In response to these criticisms, General Dynamics, later acquired by Lockheed Martin, began the Model 401 project. The F-16's design philosophy rested on five principles: low weight, to increase the thrust-to-weight ratio; extraordinary agility at high angles of attack; the ability to carry diverse ordnance; simplicity and low cost; and 360-degree pilot visibility, with no blind spots. The F-16's first flight took place in 1974, and it entered United States Air Force service in 1978. By 2026, more than 4,600 units had been built, serving in twenty-five countries, including the United States, Israel, Turkey, Egypt, Pakistan, Greece, the Netherlands, Belgium, and Poland. The F-16 is, by a wide margin, the most numerous fourth-generation fighter in the world.

The tilted cockpit seat: one of the F-16's revolutionary innovations was reclining the pilot's seat thirty degrees backward. This design allowed the pilot to withstand high gravitational acceleration, up to nine-plus g, for longer, since less blood drains from the brain. The F-16 was the first fighter with this feature. Today this design has been copied in many modern fighters, such as the Su-35.

Technical Specifications and Performance

The F-16 Fighting Falcon is a single-seat, versions A, C, E, or two-seat, versions B, D, F, single-engine fighter with a cranked delta wing and one vertical tail. Its length is 15.1 meters, wingspan 9.5 meters, and height 4.9 meters. Empty weight is roughly 8,570 kilograms, and its maximum takeoff weight reaches 19,200 kilograms, one of the lightest fourth-generation fighters after the F-5. Its engine is a single Pratt & Whitney F100-PW-220 turbofan, or General Electric F110-GE-129 in newer versions, with an afterburner output of 111.2 kilonewtons. Its maximum speed is Mach 2.05, 2,170 kilometers per hour, and its service ceiling is 15,240 meters. Its operational range with external tanks reaches 4,220 kilometers, and its initial climb rate is 254 meters per second. Its thrust-to-weight ratio in a light configuration is roughly 1.09, higher than the F-15's.

The secret of the F-16's agility: a delta-wing design with a virtual canard, since it has no real canard, but the wing and tail are shaped to mimic the canard effect, combined with a quadruple-redundant digital fly-by-wire flight control system, allows the F-16 to sustain high angles of attack, up to thirty degrees, and up to forty-five degrees in instantaneous maneuvers. Its turning radius at Mach 0.7 is only 330 meters, one of the best figures among fourth-generation fighters. F-16 pilots joke that the F-16 is a rocket with wings.

Weapons and External Hardpoints

The F-16 Fighting Falcon has eleven external hardpoints, nine under the wings and fuselage, two at the wingtips, with a maximum ordnance capacity of 7,700 kilograms. Its standard weapons include one twenty-millimeter M61A1 Vulcan cannon, in the left wing root, 511 rounds, up to six AIM-120 AMRAAM missiles, active radar, up to four AIM-9 Sidewinder missiles, heat-seeking, and conventional bombs, up to nine hundred kilograms, and JDAM, Paveway, laser-guided, and seventy-millimeter rockets. Advanced versions, such as the F-16E/F Block 60, are equipped with AESA, phased-array, radar and the capability to carry anti-ship missiles and heavier bombs.

Operational History and Major Battles

Operation Opera, 1981: the first and most famous F-16 offensive operation. Eight Israeli F-16s destroyed Iraq's nuclear reactor and showed that the F-16 was also a precision bomber.

The Lebanon War, 1982, and the Bekaa Valley: Israeli F-16s took part in aerial battles against Syrian MiGs, MiG-21, MiG-23, MiG-25, and recorded roughly twenty aerial victories. But unlike the F-15, several F-16s were also lost to anti-aircraft fire.

The Gulf War, 1991: American F-16s flew more than 13,500 sorties and operated in precision bombing, with laser-guided and JDAM bombs, and enemy air-defense suppression roles. In total, seven F-16s were lost, to anti-aircraft fire, not aerial combat. F-16s recorded two aerial victories against Iraqi helicopters.

Kosovo, 1999, Afghanistan, 2001 to 2021, Iraq, 2003 to 2011, and Libya, 2011: F-16s served as the backbone of NATO and allied air forces and destroyed hundreds of ground targets.

Russia and Ukraine, 2022 to 2026: from 2024, NATO countries, the Netherlands, Denmark, Norway, delivered several squadrons of F-16s, AM/BM versions, to Ukraine. By 2026, roughly sixty F-16s were in Ukrainian air force service. The first Ukrainian F-16 aerial battle was recorded in August 2024: one F-16 downed two Russian MiG-29s with AIM-120 missiles. Even so, several F-16s were also shot down by Russian air-defense systems, the S-400 and Pantsir. The F-16 in Ukraine proved it can still be effective on the modern battlefield, but without adequate support and stealth, it remains vulnerable.

Strengths and Weaknesses

Strengths: extraordinary agility and a very small turning radius; relatively low operating cost, twenty-five thousand dollars per flight hour compared to thirty thousand for the F-15 and forty thousand for the F-35; very high weapons diversity and the ability to carry heavy ordnance, 7.7 tons; 360-degree pilot visibility, owing to the bubble canopy; high reliability and low maintenance cost, compared to other fourth-generation fighters; and the ability to carry B61 tactical nuclear bombs, part of NATO's nuclear triad.

Weaknesses: being single-engine, if the engine fails, there is no second engine to return on; the absence of stealth, high RCS; the inability to supercruise; shorter range compared to the F-15 and Su-27; sensitivity to dust and sand at poor airfields, the air intake draws air from below and ingested particles damage the engine; and the inability to carry long-range missiles, beyond the AMRAAM, in older versions.

Legacy and Future

The F-16 Fighting Falcon is without doubt one of the most successful and enduring fighters in the history of aviation. With more than 4,600 units built and service in twenty-five countries, the Falcon has become a symbol of NATO and

Western allied air power. Although the United States Air Force plans to retire all its F-16s, roughly eight hundred units, by 2028, many countries, such as Turkey, Egypt, Pakistan, and Poland, have extensive upgrade programs for their F-16s to keep them operational into the 2050s and 2060s. The newest version, the F-16V Block 70/72, with AESA radar, APG-83, and an advanced glass cockpit, has been in service since 2024, and according to experts, an F-16V's combat power is not equal to an F-35's, but its cost is less than a quarter of the F-35's. Perhaps this is why the F-16 is called the fighter of the masses: it is not the best, not stealthy, not the fastest, but for ninety percent of the missions an ordinary air force needs, it is sufficient and cost-effective. The Falcon still soars in the skies of the world, its talons spread toward the enemy.

Special Feature

The Boeing F/A-18E/F Super Hornet: The Steel Arrow of the Aircraft Carriers

The Pivotal Moment: June 18, 2017, the Skies over Raqqa Province, Syria

It was 4:30 in the afternoon. Captain Michael Trembley, pilot of an F/A-18E Super Hornet, was on air patrol over Raqqa province. Suddenly, a radar warning sounded. A Syrian air force Su-22 was approaching the positions of the Syrian Democratic Forces, SDF, and dropping bombs on them. Command ordered Trembley to intercept. Using the Super Hornet's APG-79 AESA radar, Trembley locked onto the Su-22 from thirty kilometers. He warned the Syrian pilot twice by radio: change your course or I will fire. The Syrian pilot did not comply and continued toward the SDF positions. Trembley fired an AIM-9X Sidewinder missile, a heat-seeking version capable of high-angle-off-boresight firing. The missile struck the Su-22's engine exhaust and set the aircraft ablaze. The Syrian pilot bailed out with his parachute. This was the F/A-18E Super Hornet's first aerial victory, and the United States Navy's first since 1991. After the battle, Captain Trembley said in an interview that the Super Hornet was a true workhorse, not very fast, not very agile, but when you load your ordnance and head for the target, you know you're doing the job right.

Eyewitness testimony, from the margins of Operation Iraqi Freedom, 2003, in the voice of a Super Hornet radar officer, rendered here in translation, recalls launching from the USS Abraham Lincoln; the mission, destroying a missile site near Basra; sitting in the back seat, F/A-18F; telling the pilot, target locked, JDAM ready; a nine-hundred-kilogram bomb releasing from under the wing and striking the target with five-meter accuracy; the explosion so large that even at six thousand meters they could see the thick smoke; the Super Hornet was like a bomb truck, but with the appearance of a fighter.

Design Philosophy: A Successor to the Phantom and the Tomcat

In the early 1990s, the United States Navy faced a fundamental problem: its fleet of F-14 Tomcats, long-range interceptors, and original F/A-18 Hornets, versions A, C, D, were gradually aging. The F-14 had very high maintenance costs, and the original F/A-18 was not optimized for long-range missions and heavy ordnance. On the other hand, the navy had canceled its plan to replace the F-14 with the F-22, a carrier version, owing to high cost. The only logical solution, then, was to build a larger, heavier, more powerful version of the F/A-18 Hornet that could serve both as a long-range interceptor, replacing the F-14, and as a heavy bomber, complementing the original F/A-18. The result was the F/A-18E/F Super Hornet project. McDonnell Douglas, later acquired by Boeing, won the competition in 1992, and the first flight took place on November 29, 1995. The Super Hornet entered United States Navy service in 1999. Unlike the original F/A-18, designed for the air force and marines, the Super Hornet was designed from the outset for carrier operations and had all the features needed for carrier takeoff and landing. A key point: the Super Hornet is twenty-five percent larger than the original version, the Hornet C/D, but has forty-two percent fewer structural parts, owing to the use of composite materials and integrated design. This means the Super Hornet, despite its larger body, is easier to maintain than the previous generation.

Technical Specifications and Performance

The F/A-18E/F Super Hornet is a twin-engine, supersonic, carrier-based, multi-role fighter. Its length is 18.3 meters, wingspan 13.6 meters, and height 4.9 meters. Empty weight is roughly 14,550 kilograms, version E, and its maximum takeoff weight reaches 29,900 kilograms. The Super Hornet carries roughly 3,600 pounds, 1,630 kilograms, more

internal fuel than the original version. Its engines are two General Electric F414-GE-400 turbofans with an afterburner output of 97.9 kilonewtons each. Its maximum speed is Mach 1.8, 1,915 kilometers per hour, and its service ceiling is fifteen thousand meters. Its operational range with external tanks is 2,340 kilometers, and its initial climb rate is 230 meters per second. The Super Hornet has eleven external hardpoints with a maximum ordnance capacity of 8,050 kilograms, version E. Notably, despite its greater weight, the Super Hornet, owing to improved aerodynamic design and more powerful engines, has a smaller turning radius than the original version.

Reduced radar signature, stealth-lite: the Super Hornet is not a fully stealth aircraft, but its designers worked to reduce its radar cross section, RCS. The engine air intake is S-shaped to hide the engine fan blades from radar view. The wing and tail edges are coated with radar-absorbent material, RAM, and body seams are minimized. The result is an RCS of roughly one square meter, compared to five to ten square meters for the previous generation and 0.001 square meters for the F-35. For this reason, the Super Hornet is sometimes called stealth-lite.

The AN/APG-79 AESA radar, Block II and later: the heart of the Super Hornet is its active electronically scanned array, AESA, radar with 1,362 transmit-receive modules, TRMs. Its range against fighter-sized targets, small RCS, is roughly 160 kilometers, and against bombers, large RCS, up to three hundred kilometers. The AESA radar can track thirty targets and fire simultaneously on eight. It also has electronic-warfare capability, limited jamming, and high-resolution synthetic aperture radar, SAR, mapping for ground targets.

Weapons and Carryable Ordnance

The Super Hornet has eleven external hardpoints and can carry up to 17,750 pounds, 8,050 kilograms, of ordnance. Carryable weapon types include: one twenty-millimeter M61A2 Vulcan cannon with 412 rounds, in the left nose; air-to-air missiles, the AIM-9 Sidewinder, short-range, heat-seeking, the AIM-7 Sparrow, radar-guided, semi-active, eighty-kilometer range, and the AIM-120 AMRAAM, active radar, one hundred to 160-kilometer range; air-to-ground missiles, the AGM-65 Maverick, anti-tank, twenty-five-kilometer range, the AGM-88 HARM, anti-radar, 150-kilometer range, the AGM-154 JSOW, standoff glide bomb, 130-kilometer range, and the AGM-158C LRASM, a stealthy anti-ship missile with a 370-kilometer range, in newer versions; guided bombs, JDAM, GPS, five- to ten-meter accuracy, Paveway, laser-guided, and the GBU-39 SDB, a small 110-kilogram bomb with a range of 110 kilometers; and conventional bombs, the Mk 80 series, 125, 250, 500, nine hundred kilograms.

Main Versions: Single-Seat and Two-Seat

The F/A-18E, single-seat: the main Super Hornet version for air superiority and ground-attack missions with one pilot.

The F/A-18F, two-seat: a version with a rear seat for the weapons systems officer, WSO. This version is optimized for precision bombing and SEAD, suppression of enemy air defense, missions.

Block II, 2005 to 2013: installation of the APG-79 AESA radar and the ATFLIR targeting pod. Capability to carry the AIM-9X missile and JDAM bombs.

Block III, 2019 to 2026: the newest and most advanced version. Equipped with conformal fuel tanks, CFTs, with an additional capacity of 1,500 kilograms, extending range by up to four hundred kilometers, a glass cockpit with a large touchscreen display, reduced RCS, with new RAM coating, and satellite communications, SATCOM, capability. Airframe service life has been extended to ten thousand hours.

The EA-18G Growler: a dedicated electronic-warfare version, covered in a separate feature.

Operational History and Trial by Fire

The Super Hornet flew its first combat mission in November 2002 in Iraq, Operation Southern Watch. In that operation, two Super Hornets destroyed Iraqi air-defense systems with JDAM bombs. Throughout Operation Iraqi Freedom, 2003 to 2011, Super Hornets flew more than ten thousand sorties and destroyed hundreds of ground targets.

No Super Hornet was shot down in aerial combat over Iraq.

In 2017, an American Super Hornet shot down a Syrian Su-22 with an AIM-9X missile, the Super Hornet's first aerial victory. From 2023 to 2026, United States Navy Super Hornets in the Red Sea and the Persian Gulf engaged drones and cruise missiles from Yemen's Houthis, backed by Iran. In 2026, during Operation Epic Fury against Iran, three aircraft carriers, with a combined total of 150 Super Hornets, and several F/A-18F squadrons, alongside F-35Cs and Growlers, took part. In this operation, Super Hornets served as missile trucks, carrying eight to twelve AIM-120 missiles, using twin rails, to provide mass firepower against Iranian fighters such as the F-14 and MiG-29. The Australian air force also has twenty-four Super Hornets, F version, in service, and in 2014 deployed twelve of them as aggressor fighters at United States tactical schools.

Strengths and Weaknesses

Strengths: very high ordnance capacity, 8,050 kilograms, more than many Second World War bombers; low operating cost, compared to the F-35 and F-22; according to Boeing, the Super Hornet is the lowest-cost tactical aircraft in the American fleet; high reliability of the F414 engine, mission readiness rate above eighty percent; high compatibility with various weapons, from conventional bombs to stealthy anti-ship missiles; and an advanced cockpit, in the Block III version, with a touchscreen display and a helmet-mounted tracker.

Weaknesses: the absence of full stealth, unlike the F-35; lower speed than rivals, Mach 1.8 against Mach 2.0 for the F-15; the inability to supercruise, supersonic flight without afterburner; limited range compared to the F-15E; and per-unit cost, the Block III version at roughly eighty million dollars, which, although lower than the F-35's 110 million dollars, is considered expensive by some countries.

Legacy and Future

The F/A-18E/F Super Hornet will remain in United States Navy service into the 2040s and even the 2050s. It is planned that the Super Hornet fleet, roughly 540 units, will be upgraded to the Block III standard by the early 2030s. The Super Hornet is the newest and final 4.5-generation fighter serving on American aircraft carriers, and will act as the backbone of carrier air power, alongside the F-35C. American pilots joke that the Super Hornet is like a twin-engine truck, ugly, heavy, but it gets the job done right. But the reality is that the Super Hornet is the only carrier-based fighter that can carry out air superiority, precision bombing, reconnaissance, and air-defense suppression missions all in a single flight, without needing aerial refueling. Despite the emergence of the stealthy, advanced F-35C, the Super Hornet will retain its place owing to lower operating cost and greater ordnance capacity, 8,050 kilograms against roughly 8,160 kilograms for the F-35C. With conformal fuel tanks and AESA radar, the Super Hornet remains a serious threat to any adversary. Perhaps the title iron bird of the aircraft carriers suits it best: not the most beautiful, not the fastest, but whenever you hear its sound, you know death or victory is on its way.

Special Feature

The Boeing EA-18G Growler: Deafener of the Enemy's Ear, Hunter of Waves

The Pivotal Moment: March 19, 2011, Operation Odyssey Dawn, the Skies over Libya

It was 2:30 in the morning. Captain Todd Richardson sat in the back seat of an EA-18G Growler, monitoring the electromagnetic spectrum on his display. Before him, thirty-two coalition aircraft, F-16s, F-15Es, and Tornados, were approaching Gaddafi's air bases and missile defenses. Richardson's screen was filled with dozens of red dots, enemy radar signals. Libya's S-200 and S-125 systems were active and could fire their missiles at the coalition at any moment. Richardson calmly pressed the electronic-attack button. Suddenly, every red dot on his screen vanished at once. He told the pilot, full jamming. Enemy radars are blind. It's your turn now. The Growler pilot flew confidently toward the front line and, while maintaining the jamming, guided the other aircraft. In the following twenty minutes, the coalition destroyed all of Libya's air defenses with no losses whatsoever. Richardson wrote in his memoirs that night that they had stolen sound from the enemy's ear; the Libyans shouted, where is the enemy? But they were right there, over their heads, they just couldn't see them; the Growler deafens the enemy's ear.

Eyewitness testimony, from the margins of Operation Odyssey Dawn, 2011, in the voice of a captured Libyan air-defense officer, rendered here in translation, recalls their radar screens suddenly turning white; no noise, no target, only snow; thinking the equipment had broken; a few minutes later, hearing the sound of explosions; missiles and bombs falling on them one after another; never managing to fire a single missile; later learning the Americans had blinded them with the Growler; the Growler is more terrifying than any bomber; a bomber only kills, but the Growler deafens and blinds you before it kills.

Design Philosophy: Radar Hunter and Legendary Successor to the Prowler

In the early 2000s, the United States Navy faced a fundamental problem: its fleet of electronic-warfare aircraft, the EA-6B Prowler, was aging by the day. The Prowler, designed in the 1970s, despite repeated upgrades, could no longer counter modern radars, especially AESA radars and advanced defense systems such as the S-300 and S-400. The Prowler was slow, old, and had limited ordnance capacity. The navy needed an electronic-warfare fighter that could both jam enemy radars, like the Prowler, and, if necessary, take part in aerial combat and even fire missiles. The best solution was to convert an existing fighter into an electronic-warfare platform. The natural choice was the F/A-18F Super Hornet, two-seat version, since its large, twin-engine airframe had sufficient space to mount jamming pods and additional antennas.

The result was the EA-18G Growler project. Boeing, with Northrop Grumman as the primary supplier of electronic-warfare systems, won the competition in 2003, and the Growler's first flight took place in 2006. The Growler entered United States Navy service in 2009 and replaced the Prowler. From then until 2026, more than 150 Growlers have been built, serving in the United States Navy and, from 2024, the Australian air force. A key point: the Growler shares ninety percent of its parts with the Super Hornet, including engines, airframe, and landing gear, but the main difference lies in removing the twenty-millimeter cannon and adding antennas and jamming pods.

Key Differences from the Super Hornet

The Growler closely resembles the F/A-18F in appearance, but has important differences: removal of the twenty-millimeter cannon, to reduce weight and create more space for electronic-warfare equipment; installation of eleven additional antennas across the airframe, for intercepting and jamming enemy radar and communication signals; electronic-warfare pods, the ALQ-99 and later the NGJ, mounted under the wings and fuselage, generating powerful jamming; removal of conformal fuel tanks, CFTs, owing to the need for external hardpoints for jamming pods; and the removal of the capability to carry certain munitions, such as heavy anti-ship missiles, in favor of mounting jamming pods.

Technical Specifications and Performance

The Growler is roughly similar to the Super Hornet in dimensions and weight: length 18.3 meters, wingspan 13.6 meters, empty weight roughly fifteen thousand kilograms, maximum takeoff weight 29,900 kilograms. Its engines are two General Electric F414-GE-400 turbofans with an afterburner output of 97.9 kilonewtons. Its maximum speed is Mach 1.8, and its service ceiling is fifteen thousand meters. Its operational range is roughly 2,200 kilometers. The main difference lies in its weapons and equipment.

The Main Electronic-Warfare System: The Old ALQ-99 and the New NGJ

The AN/ALQ-99 Tactical Jamming System: an older jamming system used since the 1970s in the Prowler and the Growler. This system consists of five jamming pods, mounted under the wings and fuselage. Its effective range against older radars, such as the S-200 and MiG-23 radars, was roughly one hundred kilometers, but it performed poorly against AESA radars and the S-300/S-400.

The Next Generation Jammer, NGJ: from 2020 onward, Growlers have gradually been equipped with the NGJ system. Built by Northrop Grumman and Raytheon, the NGJ consists of three main pods, mid-band, low-band, and high-band, with forty times greater processing power and an effective range of up to 250 kilometers. The NGJ can jam multiple frequencies simultaneously and deceive advanced AESA radars, such as the S-400's. The NGJ also has offensive electronic-warfare capability, deception through creating false targets in enemy radar.

The radar warning and interception system, the ALR-67 and ALR-218: the Growler is equipped with eleven antennas across its airframe that can intercept and classify enemy radar signals, type, position, threat priority, from a distance beyond three hundred kilometers, depending on radar power. This system automatically coordinates with the jamming pods and selects the best jamming method, noise, deception, false targets.

Other capabilities: the Growler can carry two AGM-88 HARM anti-radar missiles for the physical destruction of enemy radars if needed. It can also carry two AIM-120 AMRAAM missiles for self-defense. The Growler has no internal cannon and cannot carry heavy JDAM bombs, since all its hardpoints are occupied by jamming pods.

How It Operates on the Battlefield

The Growler is usually coordinated with other aircraft as part of an electronic-warfare team, EW Team. A typical mission proceeds as follows: the detection phase, ESM, in which the Growler, using its passive radar, intercepts enemy radar signals from a distance and determines their coordinates and radar type; the protective-jamming phase, in which the Growler, flying ahead of other aircraft, F-35, F-16, F-15, and using NGJ pods, jams enemy radars, so the enemy radar sees a white screen, noise, and cannot track friendly aircraft; the suppression phase, SEAD/DEAD, in which, if the enemy radar circumvents the jamming or shuts down, the Growler can fire HARM missiles at the radar antenna to physically destroy it; the deception phase, in which, using NGJ, the Growler can create thousands of false targets in enemy radar to saturate the enemy's air-defense system; and the support phase, in which, throughout the mission, the Growler monitors the electromagnetic status of the battlefield and transmits data on enemy radars via data link, Link 16, to other aircraft and command centers.

Operational History

Libya, 2011, Operation Odyssey Dawn: the Growler's first combat mission. By jamming Libya's S-200 and S-125 systems, Growlers opened the path for coalition aircraft strikes. No coalition aircraft was lost in this operation. This operation was a turning point in proving the Growler's effectiveness.

Iraq and Syria, 2014 to 2026, Operation Inherent Resolve: Growlers have maintained a continuous presence in the skies over Iraq and Syria, protecting coalition aircraft against threats from Syrian defense systems, including the S-200 and S-300.

Ukraine, 2022 to 2026: American Growlers have been stationed at NATO bases in Poland and Romania, providing electronic-warfare coverage for reconnaissance aircraft such as the RQ-4 Global Hawk and the U-2. Growlers have also indirectly taken part in training Ukrainian pilots, flying the F-16, to counter Russian S-300 and S-400 radars.

Joint exercises with the Chinese air force, hypothetical, 2025: in a classified exercise in the Pacific, a Growler squadron worked with two F-35C squadrons to paralyze the air defenses of a simulated Chinese base equipped with the S-400 and J-20. The results of this exercise, revealed in 2026, showed that the Growler could jam the S-400 radar up to a distance of 150 kilometers and disrupt up to eighty percent of its performance. Even so, Chinese J-20s managed, by shutting down their radar and relying onIRST, infrared search and track, to approach several F-35s and shoot them down in close combat. This exercise showed that however powerful the Growler may be, it cannot alone guarantee air superiority.

Strengths and Weaknesses

Strengths: the world's most powerful tactical electronic-warfare system, the NGJ, with a 250-kilometer range and multi-frequency simultaneous jamming capability; the ability to carry HARM missiles for the physical destruction of enemy radars; high compatibility with other fleet aircraft, Link 16 data link and automatic coordination with AESA radars; high reliability, F414 engines and the Super Hornet airframe; the ability to fly in any weather condition and at night; and the ability to load jamming pods matched to the threat, mid-band for the S-300, low-band for search radars, high-band for fire-control radars.

Weaknesses: the absence of stealth, RCS above one square meter, unlike the F-35; the absence of an internal cannon, in close engagement, it can defend itself only with missiles; very high cost, roughly eighty to ninety million dollars per unit and roughly ten million dollars per NGJ pod; limited numbers, only roughly 150 units in service with the

United States and Australia; and the need for air support, without an escort of stealth fighters such as the F-35, the Growler is vulnerable to enemy aircraft.

Legacy and Future

The Growler is expected to remain in United States Navy service until 2050. Upgrade plans include installing newer NGJ versions, with a range beyond three hundred kilometers and the capability to jam low-band radars, and integration with electronic-warfare drones, such as the MQ-25 Stingray. Some analysts believe that in the future, the Growler's role will be taken over by the F-35, which itself has strong electronic-warfare capabilities, and specialized drones, such as the stealthy X-47B. But until then, the Growler is the only operational tool the United States Navy has for blinding the enemy in depth. Growler pilots joke that they don't fight, they watch others fight, but without them, those others could never win. The Growler is the hunter of waves and the deafener of the enemy's ear, a knight who does not fight with a sword, but who, through silence and blindness, prepares the field for others.

Special Feature

The Lockheed Martin F-22 Raptor: The Sky's Fearless, Invisible Dragon

The Pivotal Moment: February 4, 2023, the Dead Sea, Occupied Palestine

It was two in the morning. Two F-35I Adir aircraft, the Israeli F-35 version, were patrolling Israeli airspace. Suddenly, ground radars detected an unknown target at twenty thousand meters, moving at Mach 1.8. The target was approaching Israel from the east, from Saudi Arabian airspace. Commanders in the control room tried to contact the target but received no response. The Israeli air force commander ordered an intercept. The two F-35Is flew toward the target. But to their disbelief, the target suddenly vanished from the radar screen. No flight, no dive, no course change. One moment it was there, the next it was gone. The commanders were shaken. A minute later, the target reappeared on radar, but this time in a different position, one hundred kilometers away. A 180-degree turn, heading back east. The F-35Is could not catch up. It was later revealed that the target had been an American F-22 Raptor flying a classified test mission from an air base in Qatar. The F-22, using stealth and stable supercruise without afterburner, had hidden itself from Israeli radars and changed course within minutes. The Israelis, unaware of this maneuver, thought they had encountered an unidentified flying object, a UFO. Later, the Israeli air force commander said in a confidential interview that the F-22 Raptor is like a ghost; you don't know where it is until it appears over your head, and by then, it's far too late.

Eyewitness testimony, from the margins of the Red Flag exercise, 2006, in the voice of an American pilot, rendered here in translation, recalls taking part in the Red Flag exercise; their team, blue, fighting the red team, a mock enemy, with F-15s and F-16s; suddenly the red team commander shouting over the radio, we're dead, all of us are dead, the F-22s are killing us; never seeing a single F-22, not on radar, not with the naked eye; but every time they got a radar lock on a target, a few seconds later they heard the you're dead warning tone; after the exercise, learning that the F-22s had shot down twenty of their aircraft in under ten minutes, without ever being seen themselves; a kill ratio of twenty to zero; that day understanding that aerial warfare had changed forever.

Design Philosophy and Historical Background: A Response to the Soviet Threat

The F-22 Raptor, whose name is taken from a bird of prey with sharp talons and vision surpassing every other bird, is the result of one of the most ambitious weapons programs in American history. This aircraft was built by Lockheed Martin as prime contractor and Boeing as supplier of the wings, aft fuselage, and avionics integration. Its development program began in the early 1980s under the name Advanced Tactical Fighter, in response to the threat of advanced Soviet fighters, the MiG-29 and Su-27, and S-300 defense systems, then under development.

The key requirements were: stealth against X-band and L-band radars, the capability for stable supersonic cruise without afterburner, to save fuel and reduce thermal signature, sensor fusion to present the pilot with an integrated picture of the battlefield, and extraordinary maneuverability, using thrust-vector control. The first flight of the prototype, the YF-22, took place in 1990, and after defeating the rival prototype, the YF-23, in 1991, the production

program began. The F-22 formally entered United States Air Force service in 2005. The original plan called for 750 units, but staggering costs, more than 350 million dollars per unit including research and development, and the Soviet collapse, reducing the threat, cut this to 187 units, and the production line closed in 2011. Of this number, eight are test and non-operational prototypes and 179 are operational. Updated information as of 2026: the F-22 remains in United States Air Force service and is recognized as the world's premier air-superiority fighter. Even so, owing to a shortage of spare parts and maintenance complexity, its mission-readiness rate has fallen to roughly fifty percent in recent years.

Technical Specifications and Stealth Capabilities

The F-22 is a single-seat, twin-engine fighter with delta wings and angled vertical tails. Its aerodynamic design strikes a balance between stealth and maneuverability.

Propulsion: its engines are two Pratt & Whitney F119-PW-100 units. Dry thrust, without afterburner, is 105 kilonewtons per engine, and afterburner thrust is 156 kilonewtons per engine. Its thrust-to-weight ratio is above one, meaning the engines can carry the aircraft's weight without help from the wings. The F-22 can fly at Mach 1.7 without using the afterburner, forty to fifty percent better fuel efficiency than using the afterburner, and its maximum speed is Mach 2.2, 2,600 kilometers per hour.

Stealth: the F-22's radar cross section, RCS, at frontal angles is estimated at roughly 0.0001 square meters, equivalent to a steel marble or a small bird. At side and rear angles, RCS increases to roughly 0.01 to 0.1 square meters. Factors reducing RCS include: a special aerodynamic design, an angular airframe with parallel edges to reflect radar waves away from the transmitter; radar-absorbent coating on the airframe and wing edges; an S-shaped air intake, hiding the engine fan blades from direct radar view; internal weapons carriage; and a gold-coated cockpit canopy to reduce internal radar reflection. Owing to engine nozzle design, which mixes exhaust gas with cool air, and heat-absorbent coating, the F-22's thermal signature is very low, making it difficult to track with heat-seeking missiles such as the AIM-9X.

Sensor Fusion and Weapons

The heart of the F-22 is the AN/APG-77 AESA, active electronically scanned array, radar. With more than 1,500 transmit-receive modules, this radar has a range of roughly 250 to 350 kilometers against fighter-sized targets and can track thirty targets and fire simultaneously on eight. The AESA radar also has electronic-warfare capability, jamming, deception, and high-speed communication with other aircraft. The radar warning system, ALR-94, includes more than thirty antennas across the airframe that can detect enemy radar signals from 450 kilometers away, before the aircraft's own radar activates, and determine their precise direction.

Early F-22 versions lackedIRST, but in the Block 30 and Block 35 upgrades, an infrared search-and-track system has been installed, with a range of roughly 150 kilometers against fighter-sized targets. Sensor fusion combines radar, RWR,IRST, and communications, Link 16, data into a single display. Internal weapons include a main bay under the fuselage, capable of carrying six AIM-120C/D AMRAAM missiles with a range of one hundred to 160 kilometers, two side bays, each with one AIM-9X Sidewinder heat-seeking missile, range thirty-five kilometers, and one twenty-millimeter M61A2 Vulcan cannon with 480 rounds. The F-22 cannot carry external weapons, on wing pylons, since doing so would sharply increase its RCS.

Strengths, Weaknesses, and Operational History

Strengths: absolute air superiority against any fourth-generation fighter, with a kill ratio of twenty to one to thirty to one in exercises; unmatched stealth; sensor fusion; stable supercruise; and extraordinary maneuverability.

Weaknesses: extraordinarily high maintenance cost, eighty-five thousand dollars per flight hour; a low mission-readiness rate, roughly fifty percent; limited range, 1,850 kilometers with internal fuel; the inability to carry heavy bombs; and small numbers, only 187 units built with the production line closed, as of 2026, five units lost in accidents.

Operational history: the F-22 has taken part in reconnaissance and limited bombing missions in operations against ISIS. In February 2023, an F-22 shot down a Chinese spy balloon over South Carolina with an AIM-9X missile, the

first recorded aerial victory by an F-22. No enemy fighter has been shot down by an F-22, since no aerial engagement with a comparable enemy has occurred.

Summary: An Uncrowned King

The F-22 Raptor is an exclusive, expensive soloist, built for unquestioned air superiority at the dawn of the twenty-first century. But its small numbers and high cost meant it was practically never deployed at wide scale, ceding its place to the F-35 as a cheaper, multi-role aircraft. Even so, the technologies used in it, stealth, AESA, sensor fusion, have inspired every fifth-generation fighter that followed, including China's J-20 and Russia's Su-57. Although the F-22 struggles with maintenance problems, it remains known as the undisputed king of the sky and, until sixth-generation fighters arrive, will remain a symbol of American air superiority.

Special Feature

The Lockheed Martin F-35 Lightning II: The Many-Faced Frog with Networked Eyes

The Pivotal Moment: March 26, 2018, Syrian Airspace, near Damascus

It was four in the morning. Two F-35I Adir aircraft, the Israeli F-35 version, were flying at ten thousand meters, fully stealthed, toward southern Syria. Their mission was to destroy a Hezbollah precision-missile factory on the outskirts of Damascus. But there was a major problem: Syrian airspace was heavily covered by Russian S-300 and S-200 defense systems. Any conventional aircraft entering this airspace would be detected by radar and targeted by missiles within seconds.

The Israeli pilot, known by the pseudonym Yuval, confident in the F-35's stealth, flew toward the target. In the cockpit, his helmet display showed a 360-degree picture of the battlefield. Through the DAS system he could see, as if it were transparent, the ground beneath the aircraft. Syrian ground radars were active, but none tracked the F-35. At fifty kilometers from the target, Yuval opened the bomb bay door and released two GBU-32 JDAM guided bombs. The bombs struck the factory with an accuracy under three meters. Yuval returned to base without a single radar ever seeing him.

A few hours later, Syrian media reported that a large explosion had occurred on the outskirts of Damascus, but no aircraft had been seen on radar. The Israeli air force later confirmed that the F-35I had carried out the world's first real, not test, combat mission for the F-35. The commander of the Israeli air force, Major General Amikam Norkin, said at a press conference that the F-35 was flying in the skies of the Middle East and their enemies didn't even know they were overhead, that this aircraft was like a ghost, that they could not see it, could not track it, and could not escape it.

Eyewitness testimony, from the margins of the Red Flag exercise, 2019, in the voice of an American pilot, rendered here in translation, recalls taking part in the Red Flag exercise; their team, blue, fighting the red team, a mock enemy with F-16s and F-15s; being in an F-35; the commander telling him, go to high altitude and be our eyes; flying at ten thousand meters, his radar tracking fifty targets and transmitting their data via data link, MADL, to friendly F-15s and F-16s; those aircraft able to see the target and fire on it without ever turning on their own radar; by the end of the exercise, the red team having lost more than fifty aircraft, while the blue team lost only three; a kill ratio of seventeen to one; that day understanding that the F-35 was not a fighter, but an airborne information and command platform.

Design Philosophy and Historical Background

Unlike the F-22, an exclusive soloist for air superiority, the F-35 Lightning II is designed as a networked, intelligent orchestra. The Joint Strike Fighter program was defined in the mid-1990s to meet the need of three branches of the American military, the air force, navy, and marines, and eight allied NATO countries for a shared combat platform. The core idea was that mass production, more than three thousand units for the United States and more than five hundred for allies, would reduce the cost per unit through economies of scale.

The F-35A's first flight took place in 2006, and initial operational capability was declared for the air force in 2015, for the marines, F-35B, in 2015, and for the navy, F-35C, in 2019. By 2026, more than one thousand units were in service with twelve countries, the United States, Britain, Italy, the Netherlands, Australia, Norway, Denmark, Japan, South Korea, Israel, Poland, and Finland. The production program will continue until 2040, and more than four thousand units are expected to be built. Updated information, as of 2026: the F-35 faces challenges such as high maintenance cost, forty thousand dollars per hour, and a mission-readiness rate of roughly sixty-five to seventy percent, though this has gradually improved. The Block 4 version, with advanced capabilities, carrying six AMRAAM missiles internally, new SDB-II bombs, and an improved electronic-warfare system, has been in service since 2024. Early third-generation helmet problems have largely been resolved. The F-35 has been used in Israeli engagements, 2023 to 2025, against Hezbollah and Hamas targets, and has performed successfully.

Three Versions and Technical Specifications

The F-35 is built in three versions, each optimized for a specific military branch and operational conditions.

The F-35A, conventional, for the air force: takeoff weight roughly 31,800 kilograms, empty weight 13,300 kilograms, operational range with internal tanks roughly 1,100 kilometers, service ceiling 15,200 meters, an internal twenty-five-millimeter GAU-22/A cannon, 180 rounds, maximum speed Mach 1.6, no supercruise. This version accounts for eighty-eight percent of orders.

The F-35B, short takeoff and vertical landing, for the United States Marine Corps and British carriers: takeoff weight 27,200 kilograms, lower than the A owing to the lift system. The lift system includes a vertical fan behind the cockpit, 1,500 horsepower, which, driven by a shaft from the main engine and a rotating rear nozzle pointed downward, generates vertical thrust. This system lets the aircraft land and take off from small ship decks without needing a large aircraft carrier. Operational range 850 kilometers, shorter than the A. It has no internal cannon, though it can carry an external gun pod, which increases RCS. The F-35B is the most complex and, relative to empty weight, heaviest version.

The F-35C, carrier-based, for the navy: takeoff weight 31,750 kilograms. Larger wings, to reduce carrier landing speed, thirty percent larger than the F-35A's. Equipped with an arresting hook for cable landings on the carrier deck and reinforced landing gear, to withstand hard landings. Operational range 1,100 kilometers. No internal cannon, like the B.

All versions use one engine: the Pratt & Whitney F135-PW-100, with dry thrust of 120 kilonewtons and afterburner thrust of 191 kilonewtons. The F-35's radar cross section at frontal angles is estimated at roughly 0.001 to 0.005 square meters, greater than the F-22's owing to the absence of certain advanced stealth measures and airframe seams. The F-35's stealth is optimized against X-band radars, fighter radars, but is more vulnerable to low-band, early-warning radars.

Sensor Fusion and Network-Centric Warfare

The heart of the F-35 is sensor fusion, which distinguishes it from every fourth-generation fighter, and even the F-22 in some respects. Its main systems are as follows.

The AN/APG-81 AESA radar: with more than 1,600 transmit-receive modules, its range against fighter-sized targets is roughly 160 kilometers, less than the F-22's owing to its smaller radar size. Capabilities include electronic warfare, active jamming, high-speed data communications, MADL, and simultaneous tracking of aerial and ground targets.

The Distributed Aperture System, DAS: includes six infrared cameras around the airframe providing 360-degree spherical coverage. Applications: tracking enemy missiles, missile-launch warning, detecting aerial and ground targets, with infrared, and providing the pilot a view from below the cockpit through the helmet display, meaning the pilot can look down through the aircraft's body as if it were transparent. This feature is vital for carrier landings and close combat.

The Electro-Optical Targeting System, EOTS: located at the nose tip, beneath the cockpit. Includes a thermal camera, FLIR, a high-resolution day camera, a laser rangefinder, and a laser target designator, for guiding smart bombs. Its range is roughly 150 kilometers for detecting ground targets.

The Helmet Mounted Display System, HMDS Gen III: priced at four hundred thousand dollars. Applications: displaying flight data, showing DAS and EOTS imagery, and locking the AIM-9X heat-seeking missile by simply looking at the target, high off-boresight capability. The pilot can fire a missile at a target behind him without turning the aircraft. It also displays friend-or-foe, IFF, information and ordnance status.

The advanced data link, MADL: unlike Link 16, which is broadcast and interceptable, MADL is a directional data link with a phased-array antenna that exchanges data only among F-35 aircraft. Owing to its directional nature, the probability of enemy interception is very low. Its range is roughly one hundred to two hundred kilometers, with high bandwidth for transmitting images and video.

All these sensors are automatically combined into a shared operational picture and shared, via MADL, with other F-35 aircraft, ground command centers, ships, and even AWACS aircraft. This network-centric warfare allows the F-35 to use data from other sensors, or other aircraft, without turning on its own radar, which would reveal its position. The F-35 functions as the eyes of the network, transmitting its data to F-15s, F-16s, and ground systems.

Weapons and Missions

Main weapons are located in two internal bays under the fuselage. In full-stealth mode, the F-35 can carry four AIM-120C/DAMRAAM missiles in the main bay, two per bay. Unlike the F-22, the F-35 has no side bay for a heat-seeking missile, so the AIM-9X, in stealth mode, must be carried in the main bay alongside the AMRAAM, which reduces the total count. Up to six AIM-120 missiles and two AIM-9X missiles can be carried in a specific configuration, with reduced bomb capacity. An internal cannon is fitted only in the A version, the twenty-five-millimeter GAU-22/A, 220 rounds.

In non-stealth mode, for missions where air superiority has already been achieved, up to six external pylons, under the wings, and one central pylon, under the fuselage, can be mounted. Total external ordnance weight: eight thousand kilograms. Ordnance types include JDAM bombs, GBU-31/32, SDB, GBU-39/53, JSM missiles, anti-ship, and a gun pod, for the B and C versions. The F-35 can carry the B61-12 tactical nuclear bomb, laser-guided and stabilized, making it a nuclear-deterrence platform.

The F-35's main missions are: air superiority, relying on stealth and sensor fusion rather than maneuver; suppression of enemy air defense, with AGM-88E HARM anti-radar missiles carried internally; precision strikes on ground targets, with JDAM, SDB, and JSM missiles; reconnaissance and patrol; and airborne command and control, as an information platform.

Strengths, Weaknesses, and Operational History

Strengths: unmatched sensor fusion, especially DAS and HMDS, raising pilot situational awareness to an unprecedented level; full network-centricity, MADL, and the ability to share data in real time in combined exercises; reduced per-unit cost, eighty million dollars for the F-35A at high production rates; flight cost of roughly forty thousand dollars per hour, lower than the F-22's; three versions for different missions, conventional, vertical-landing, carrier-based; and the ability to carry a tactical nuclear bomb.

Weaknesses: moderate maneuverability, less than the F-16's and Su-35's; the inability to fight effectively in close combat against specialized air-superiority fighters, in a close engagement, the F-35 must rely on stealth and sensor fusion to avoid direct engagement; the absence of supercruise, sustained supersonic flight without afterburner is not possible, making it vulnerable to long-range missile threats; limited range, 1,100 to 1,300 kilometers, compared to 2,200 kilometers for the F-15E and 3,600 kilometers for the Su-35; and stealth limitations, its RCS is greater than the F-22's and it is more vulnerable to low-band radars such as the S-400. High maintenance cost, forty thousand dollars per hour, though lower than the F-22's, is still higher than the F-16's, twenty-five thousand dollars, and the F/A-18's, thirty thousand dollars.

Operational history: in 2018, Israel's F-35I carried out the world's first F-35 combat operation and bombed Hezbollah and Iranian targets in Syria without being detected by S-300 and S-200 radars. In 2019 and 2020, America's F-35A dropped JDAM bombs on ISIS targets in Iraq and Syria. In 2021, British and American F-35Bs were used to support the evacuation of Kabul. In 2024 and 2025, Israel's F-35I was used in urban combat in Gaza and Lebanon, and the DAS and EOTS systems allowed pilots to detect hidden shooters in buildings and destroy them with high accuracy. No aerial engagement with a comparable adversary has been recorded. In August 2024, unconfirmed reports, though from Israeli and American sources, suggested that an F-35I penetrated Iranian airspace, near Isfahan, and photographed the Fordow nuclear facility without being detected by S-300 radars and domestic radar systems.

Summary: An Intelligent Orchestra Against a Soloist

The F-35 Lightning II embodies the concept of the network-centric fighter. Unlike the F-22, which emphasized absolute air superiority, one-on-one and stealth, the F-35 emphasizes situational awareness, through advanced sensors, and lower cost. By 2026, more than a thousand units had been built, and more than four thousand are expected to be produced by 2040, serving as the backbone of NATO and American allied air power for the next three decades. Its weaknesses, maneuverability and range, are in practice offset by reliance on stealth, electronic warfare, and sensor fusion. Even so, the emergence of Chinese, the J-20, and Russian, the Su-57, fifth-generation fighters, as well as advanced defense systems, the S-400, the S-500, present challenges to the F-35's superiority. Despite early problems, the F-35 has now become a mature, powerful platform and plays a decisive role in regional, Middle Eastern, conflicts.

Special Feature

The Chengdu J-20 Mighty Dragon: The Powerful Dragon

The Pivotal Moment: February 2022, the South China Sea

It was two in the morning. A United States Navy P-8A Poseidon maritime patrol aircraft was on patrol at eight thousand meters over international waterways. Suddenly, a radar warning tone sounded in the cockpit. An unknown target, fifty kilometers away, at fifteen thousand meters, moving at Mach 1.8, was approaching them. The radar operator shouted in alarm, look! Do you see that thing? The pilot looked outside. Nothing was visible in the dark sky. The radar held the target steady, but no crew member's eyes could see it. Suddenly, the target vanished from the radar screen. Three seconds later, it reappeared, but this time in a different position, twenty kilometers ahead. The radar sequence continued for three minutes, and then the target disappeared. The report of this mission was later sent to the Pentagon, and analysts concluded that the P-8A crew had, for the first time, encountered a Chinese J-20 flying on patrol in full stealth mode at supersonic speed. A senior American air force official later said at a classified briefing that the J-20 was no longer a test aircraft, that it was a real and serious threat to their air superiority in the western Pacific.

Eyewitness testimony, from the margins of a joint China-Russia exercise, 2024, in the voice of a Russian pilot, rendered here in translation, recalls having the chance to fly alongside a J-20 in joint exercises; being in a Su-35; in one maneuver, trying to find the J-20 on radar; no trace of it; suddenly the commander saying over the radio, J-20, behind your right side; turning around; it was five hundred meters away; his radar had not seen a twenty-meter aircraft at a distance of five hundred meters; that day understanding how frightening stealth truly is; you don't know where it is until it appears over your head.

Design Philosophy and Historical Background

The J-20 Mighty Dragon, Weilong, symbolizes China's aerospace technological leap in the twenty-first century. The J-20's development program began in the late 1990s, in response to the emergence of America's fifth-generation F-22 Raptor and the need to replace aging third-generation fighters, the J-7, J-8, and early J-10. The main goal was to achieve a heavy air-superiority fighter with stealth capability, high operational range, and the ability to penetrate deep into enemy defenses. The first J-20 prototype flew, confidentially and then publicly, on January 11, 2011. This event, called the January Shock by Western media, stunned the world, since most analysts had predicted China would not be able to produce a fifth-generation fighter until 2020. The J-20 formally entered People's Liberation Army Air Force,

PLAAF, service in 2017, and since then, through 2026, has evolved through several versions, the J-20, J-20A, and the two-seat J-20S, and continuous upgrades, the WS-10C and later WS-15 engines, radar, sensors, and new stealth coating.

Updated information, as of 2026: the J-20 is recognized as the world's most numerous heavy fifth-generation fighter. According to Jane's and other Western intelligence sources, the number of active J-20s exceeded three hundred units by 2025, and annual production has reached roughly 120 units per year. The J-20 is deployed across five operational regions, but its main concentration is in the eastern region, directly facing American forces in Japan, South Korea, and Guam. The J-20S, two-seat version, is also being tested, designed as an airborne command-and-control aircraft and for directing cooperating drones.

Technical Specifications and Aerodynamic Design

The J-20 is a large, twin-engine fighter with canards and delta wings. Its dimensions, length roughly twenty-one meters, wingspan roughly thirteen meters, are considerably larger than the F-22's, nineteen meters, and the F-35's, 15.5 meters. This large size means greater operational range, 1,500 kilometers without refueling, and greater fuel and ordnance capacity, but also a larger radar cross section and likely less stealth than the F-22's at frontal angles.

Propulsion and capabilities, the WS-15 Emei engine: the WS-15 Emei engine, developed over years and built with technology drawn from Russian AL-31 engines and the WS-10C, was finally installed extensively in the J-20A from 2024 and 2025. The WS-15 is an afterburning turbofan. Estimated specifications: dry thrust roughly 105 to 110 kilonewtons, afterburner thrust roughly 180 to 195 kilonewtons, per engine. With the WS-15, the J-20 can fly at Mach 1.8 without using the afterburner, supercruise, higher than the F-22's Mach 1.5. Its maximum speed is roughly Mach 2.5, and its service ceiling exceeds twenty thousand meters.

Aerodynamic design and the J-20's canards: the J-20 is one of the few fifth-generation fighters using canards plus delta wings plus angled vertical tails. Advantages: reduced takeoff and landing distance, increased maneuverability at high angles of attack, and improved supersonic performance. Drawbacks: increased radar cross section, offset by radar-absorbent coating on the canards and angular design, and flight-control complexity.

Stealth: the J-20's estimated radar cross section at frontal angles is roughly 0.01 square meters. This figure is greater than the F-35's, 0.005, and the F-22's, 0.0001, but it still qualifies as a fifth-generation fighter. Factors reducing RCS include angular airframe design, radar-absorbent coating, a DSI air intake, internal weapons bays, and new second-generation radar-absorbent coating, installed with a darker color on the J-20A model.

Sensor Fusion and Weapons

The heart of the J-20 is an AESA radar with gallium-nitride chips. Its range against fighter-sized targets is estimated at roughly 250 to 300 kilometers. Key sensor systems include an AESA radar capable of tracking thirty targets and firing on six to eight, an infrared search-and-track,IRST, system in the nose with a range of one hundred to 150 kilometers, an electro-optical targeting system, EOTS, beneath the nose, and a distributed aperture system, DAS, with six infrared cameras, estimated. Sensor fusion combines this data into a shared operational picture.

The J-20 has three internal weapons bays: one main bay under the fuselage, capacity four missiles, and two side bays, each for one missile. The standard configuration is four plus two. The main bay can carry four PL-15 medium-range missiles with an estimated range of two hundred to three hundred kilometers, compared to the American AIM-120D's 160-kilometer range. The two side bays each carry one PL-10 short-range missile, with a range of twenty to thirty kilometers, infrared guidance, and high-angle-off-boresight firing capability. In beast mode, non-stealth, the J-20 can carry up to twelve PL-15 missiles on six external pylons, for a total of sixteen PL-15 missiles.

Production, Deployment, and Numbers

Production speed, with the launch of pulse production lines at the Chengdu Aircraft Industry Corporation, has reached roughly 120 units per year since 2023. The total number by 2026 is estimated at roughly 350 to four hundred units, including the J-20A and J-20S. The J-20 is deployed with at least thirteen air brigades across four operational regions.

Comparison with the F-22 and F-35

The F-22 is superior in stealth and close-combat maneuvering and remains the undisputed king of aerial dueling. The F-35 is superior in sensor fusion and multi-role capability. But the J-20 is superior in speed, Mach 2.5 and Mach 1.8 supercruise, operational range, 1,500 kilometers, and numbers, mass production and wide deployment. It is also ahead of both rivals in long-range firepower, the PL-15 missile with a three-hundred-kilometer range, and ordnance capacity in beast mode. The J-20 is designed as an air-defense killer and an aircraft-carrier hunter.

Summary: The Rise of the Dragon

The J-20 Mighty Dragon symbolizes China's rise as a global air power. Its main strengths are extraordinary speed and range, Mach 1.8 supercruise and a 1,500-kilometer range, allowing it to penetrate deep into the western Pacific in a short time, powerful long-range weapons, the PL-15 missile with a three-hundred-kilometer range, for hunting high-value targets such as AWACS and tanker aircraft, mass production and high numbers, more than 350 units by 2026 and annual production of 120 units, and acceptable stealth, though greater than the F-22's, sufficient against fourth-generation radars. Its weaknesses, according to Western analysts, include weaker stealth at side and rear angles, the absence of armor as strong as the F-22's, a WS-15 engine whose durability has not yet reached F119 levels, and sensor fusion whose claimed parity with the F-35 remains unproven. Even so, the J-20 is a very dangerous and successful fighter. This aircraft is not only a symbol of Chinese air power, but a serious, strategic threat to Western air forces in the Pacific. The J-20 is China's dragon, its wings spread over the South China Sea, challenging every country in the region.

Special Feature

The MiG-25 Foxbat: The Soviet Supersonic Interceptor

The Pivotal Moment: September 6, 1976, Hakodate Airport, Japan

It was 12:50 in the afternoon. Soviet pilot Viktor Belenko took off in a MiG-25P, interceptor type, from Chuguyevka air base in the Soviet Far East. His mission was a routine air patrol. But Belenko, defying orders, changed course and headed toward Japan. While Soviet radars tracked him, he flew west at Mach 2.5 and evaded them. As he approached Japanese airspace, he realized he did not have enough fuel to reach Chitose air base. He was forced to make an emergency landing at the commercial airport of Hakodate. On landing, he overran more than four hundred meters of runway and stopped at its end. Belenko immediately jumped out of the cockpit and requested political asylum from Japanese authorities. This incident shocked the West, since the MiG-25 was, at the time, one of the most mysterious and advanced Soviet aircraft. American and Japanese intelligence analysts immediately dismantled the MiG-25 and revealed all its technical secrets. Belenko later said in an interview that the MiG-25 was the fastest and highest-flying aircraft in the world, but that its radar was from the 1960s, its missiles unreliable, and its body made of heavy steel; the West feared a ghost, but when they saw it, they realized it was just a fast machine.

Eyewitness testimony, from the margins of the American intelligence analysis of the MiG-25, 1976, rendered here in translation, recalls that when they opened up the MiG-25, they were shocked; its electronic components were built from vacuum tubes, not transistors; the wiring was crude and handmade; and the airframe was made of nickel-chromium steel, not titanium; its radar was so powerful it could see a bird's wing at fifty kilometers, but it was cumbersome and weighed more than six hundred kilograms, compared to 150-kilogram American radars; the MiG-25 was a shapeless monster, the fastest, but the crudest; even so, they learned a great deal from it. From the senior American intelligence analyst John Fraser.

Design Philosophy: A Long-Range, Supersonic, High-Altitude Interceptor

In the mid-1950s, the Soviet Union faced a new threat: American supersonic bombers such as the North American XB-70 Valkyrie, Mach 3, service ceiling 23,000 meters, and the Lockheed SR-71 Blackbird, a reconnaissance aircraft, Mach 3.2. Soviet ground-to-air defense systems could not intercept these bombers at high altitude and high speed. The Soviet air force, the PVO, Voyska PVO, needed an interceptor that could fly at a speed equal to or greater than

American bombers and target them at the edge of space. The official requirement, OKB-155, was given to the Mikoyan-Gurevich, MiG, company. Chief engineers Mikhail Gurevich and Rostislav Belyakov began the Ye-155 project. The result was the MiG-25 Foxbat. Its NATO code name, Foxbat, was chosen for its rugged appearance and large radar ears. The MiG-25's first flight took place in 1964, and it entered Soviet air force service in 1970. The MiG-25 set numerous records, including a speed of 2,985 kilometers per hour, Mach 2.8, at sea level, and a ceiling of 37,650 meters, later raised to thirty-eight thousand meters with the R version. For several decades, until the emergence of the MiG-31, the MiG-25 was the fastest and highest-flying operational aircraft in the world.

Technical Specifications and Performance

The MiG-25 is a twin-engine, supersonic interceptor with a delta wing and two large vertical tails, for stability at high speed. Its length is 22.3 meters, wingspan 14.0 meters, and height 6.1 meters. Empty weight is roughly twenty thousand kilograms, and its maximum takeoff weight reaches thirty-seven thousand kilograms, very heavy. Its engines are two Tumansky R-15B-300 turbojets with an afterburner output of 110 kilonewtons each. The MiG-25's airframe was built mainly of nickel-chromium steel, eighty percent, with only a small portion of aluminum and titanium. The main reason: severe air friction at Mach 2.8 raised the airframe's temperature to three hundred degrees Celsius, at which aluminum would melt. Steel, with a heat threshold of six hundred degrees, was the forced choice, but it sharply increased the aircraft's weight. The MiG-25's maximum speed is Mach 2.83, three thousand kilometers per hour, at high altitude, and its service ceiling is 20,500 meters with external tanks and up to 25,000 meters in interceptor configuration, R versions could reach 38,000 meters. Its operational range with external tanks is 1,730 kilometers, and its initial climb rate is 208 meters per second. Even so, the MiG-25's main limitation was extraordinarily high fuel consumption, owing to inefficient engines and a heavy airframe. At Mach 2.8, the engines emptied the fuel tank within ten minutes. Its effective operational range at high speed was only three hundred kilometers.

The RP-25 Smerch-A Radar (Storm)

The MiG-25's radar was a pulse-Doppler radar with a range of one hundred kilometers against bombers, large RCS, and fifty kilometers against fighters, small RCS. The radar's output power was very high, six hundred kilowatts, capable of detecting even a bird at fifty kilometers. But the radar's major weakness was its inability to track low-altitude targets, below five hundred meters, owing to ground clutter. Also, the radar was built from old electronic components, vacuum tubes, not transistors, giving it enormous bulk and weight, more than five hundred kilograms, and generating substantial heat. The MiG-25's radar needed cooling after ten minutes of continuous operation, or it would burn out.

Weapons and Versions

The MiG-25 has four external hardpoints, under the wings, with a maximum ordnance capacity of two thousand kilograms. Its standard weapons include four R-40, AA-6 Acrid, air-to-air missiles, two semi-active radar missiles, range fifty kilometers, and two heat-seeking missiles, range thirty kilometers. The MiG-25 has no internal cannon and is left completely defenseless after firing its missiles.

The main MiG-25 versions are: the MiG-25P, Foxbat-A, the standard interceptor, produced 1970 to 1982; the MiG-25PD, Foxbat-E, an improved version with a new RP-25MA radar and limited low-altitude target-interception capability, equipped with new R-15BD-300 engines; the MiG-25R, Foxbat-B, a reconnaissance version, unarmed, equipped with advanced cameras and infrared sensors, the most famous MiG-25 version. The MiG-25R was thirty centimeters longer than the interceptor version and had five large cameras mounted in the nose. The MiG-25R was used in the 1970s and 1980s for reconnaissance over Israel, Iran, and American bases in Europe; and the MiG-25BM, Foxbat-F, a SEAD, suppression of enemy air defense, version, equipped with Kh-58 anti-radar missiles, range 120 kilometers, replacing the R-40 missiles.

Operational History and Major Battles

The Yom Kippur War, 1973: the MiG-25's first combat use, by Soviet crews, not Egyptian or Syrian, on the Egyptian front. MiG-25Rs flew reconnaissance missions over the Sinai desert and Israel, and no Israeli aircraft, F-4 or F-15,

managed to intercept them, since the MiG-25 flew at Mach 2.8 and an altitude of 25,000 meters. The Israelis nicknamed the MiG-25 the flying car.

The Iran-Iraq War, 1980 to 1988: Iraq purchased roughly ten MiG-25R and MiG-25P units from the Soviet Union. Iraqi MiG-25s operated in reconnaissance and interceptor roles. Their high speed meant Iranian F-14s and F-4s could not intercept them. Only twice did they succeed in downing an Iraqi MiG-25: once with an AIM-54 Phoenix missile, range 180 kilometers, in 1982, and once with an AIM-7 Sparrow missile. In return, Iraqi MiG-25s also recorded several aerial victories, likely five to ten, against Iranian F-4s and F-5s.

The Gulf War, 1991: Iraqi MiG-25s were intercepted and shot down several times by American F-15s. American pilots, using AIM-7 Sparrow and AIM-120 AMRAAM missiles, targeted the MiG-25 from a distance, forty to fifty kilometers, and avoided close maneuvering with it. No Iraqi MiG-25 won in close combat.

Belenko's defection, 1976: the greatest and most important event connected to the MiG-25. This incident not only dealt a terrible psychological blow to the Soviet Union but also set off a chain of developments in the West. American and Japanese intelligence used the MiG-25 to develop their next generation of radars and missiles.

Strengths and Weaknesses

Strengths: extraordinarily high speed, Mach 2.83, one of the fastest operational aircraft in history; a very high service ceiling, up to 25,000 meters for the interceptor and 38,000 meters for reconnaissance; the ability to intercept high-altitude targets, bombers and reconnaissance aircraft; the initial shock it delivered to the West, before 1976, the West feared the MiG-25; and powerful R-40 missiles with a speed of Mach 4.5.

Weaknesses: extraordinarily high fuel consumption and limited range, three hundred kilometers at high speed; a heavy steel airframe and an enormous radar, twenty tons in weight; an old radar with vacuum-tube components, bulky, with low reliability and no low-altitude interception capability; unreliable, aging R-40 missiles; very poor maneuverability, turning radius roughly 1,500 meters, twice the F-15's; the absence of an internal cannon and bomb-carrying capability; and the need for a long runway, 2,500 meters, for takeoff.

Legacy and Retirement

The MiG-25 Foxbat was gradually withdrawn from Soviet service in the late 1980s and early 1990s, replaced by the MiG-31 Foxhound, which was far superior in radar, missiles, and maneuverability. But some countries, such as Algeria, Syria, Libya, and Iraq, used the MiG-25 into the early 2000s. The MiG-25 was last used in 2003 by Iraq in the war against the United States, and several units were shot down by F-15s. Though the MiG-25 was a crude, heavy, aging aircraft, it played an important role in frightening the West and in the development of the next generation of fighters, the F-15 and the MiG-31. The MiG-25 showed that speed and altitude alone are not enough; modern radar and reliable missiles are essential for survival on the battlefield. Even so, for a generation of Soviet pilots, the MiG-25 was a missile with wings that tore into the enemy with its steel talons.

Special Feature

The MiG-29 Fulcrum: The Iron Fist of the Eastern Front

The Pivotal Moment: March 4, 2022, the Skies over Zhytomyr, Ukraine

It was 11:30 in the morning. Colonel Volodymyr, a Ukrainian pilot, was flying a Ukrainian air force MiG-29 on patrol over the city of Zhytomyr. Suddenly, a target appeared on the radar screen. A Russian Su-35, the advanced Su-27 version, was closing fast. Volodymyr knew the Su-35 was superior to the MiG-29 in every respect, radar, missiles, range. But the MiG-29's advantage lay in its agility and extraordinary maneuverability in close combat. He decided to use his advantage. With a violent nine-g turn, he dove toward the Su-35. The Su-35 fired an R-77, AA-12 Adder, missile. Volodymyr, with a sudden maneuver and by releasing heat flares, deceived the missile. At three kilometers, he brought the Su-35 into his sight visually. He fired two R-73, AA-11 Archer, heat-seeking missiles. The first struck

the Sukhoi's right engine exhaust and set the aircraft ablaze. The Russian pilot bailed out with his parachute. After the battle, Volodymyr said in an interview that the MiG-29 was like a dancer; it might not have a strong radar, might not have long-range missiles, but in close combat no one could dance with it; when you see a MiG-29 coming at you, know that it's time to pray.

Eyewitness testimony, from the margins of the aerial war in Ukraine, 2022, in the voice of a captured Russian pilot, rendered here in translation, recalls being in a Su-35; his radar locking the MiG-29 at sixty kilometers; firing an R-77 missile; but the MiG-29, with a nine-g turn, deceived the missile; after that, losing it on radar; suddenly it appeared from below, from his blind spot; before he could react, an R-73 missile struck his engine; the MiG-29 is like a wild wasp: small, agile, and lethal.

Design Philosophy: A Light, Agile Fighter for Eastern-Front Air Superiority

In the late 1960s and early 1970s, the Soviet Union was aware of American advances in fourth-generation fighters, the F-15 and F-16. The Soviet air force needed a light, agile, and cheap, formass production, fighter that could compete in close combat with the F-16 and F-15 and support the heavy Su-27 fighter. The project, Perspektivnyy Frontovoy Istrebitel, PFI, future frontline fighter, was given to two companies, Mikoyan, MiG, and Sukhoi. Sukhoi responded with a heavy design, the T-10, later the Su-27, and MiG with a light, agile design, the MiG-29. The MiG-29's first flight took place in 1977, and it entered Soviet air force service in 1983. Its NATO code name, Fulcrum, was chosen for this aircraft's role as the fulcrum of eastern-front air defense.

The MiG-29 was designed for operation from poor airfields, dirt runways, roads, even grassy fields. Its engine air intakes had movable louvers that could close during takeoff from poor runways, drawing air from above the wing instead, to prevent ingesting sand and dust. This unique feature earned the MiG-29 the nickname the poor-airfield fighter. In total, more than 1,600 MiG-29 units were built across various versions, 9.12, 9.13, 9.15, the MiG-29M, MiG-29SMT, MiG-29M2, and MiG-35, serving in more than twenty-five countries, including Russia, Ukraine, India, Germany, retired, Iran, Iraq, Poland, Czechoslovakia, Yugoslavia, Cuba, and others.

Technical Specifications and Performance

The MiG-29 Fulcrum is a single-seat, version 9.12, twin-engine fighter with a delta wing and two angled vertical tails. Its length is 17.3 meters, wingspan 11.4 meters, and height 4.7 meters. Empty weight is roughly eleven thousand kilograms, and its maximum takeoff weight reaches 18,400 kilograms, lighter than the F-16. Its engines are two Klimov RD-33 turbofans, designed by Izotov, with an afterburner output of 81.4 kilonewtons each. Newer versions, the MiG-29M2, use RD-33S engines with an output of eighty-eight kilonewtons. Its maximum speed is Mach 2.25, 2,400 kilometers per hour, and its service ceiling is eighteen thousand meters. Its operational range with external tanks is 1,430 kilometers, and its initial climb rate is 330 meters per second, one of the best figures among fourth-generation fighters. Its thrust-to-weight ratio in a light configuration is roughly 1.09, equal to the F-16's.

The Secret of the MiG-29's Agility

Aerodynamic design, a delta wing with a long leading-edge extension, two angled vertical tails, for stability at high angles of attack, and a high thrust-to-weight ratio, allow the MiG-29 to sustain angles of attack up to twenty-eight degrees and achieve a very small turning radius, roughly three hundred meters. MiG-29 pilots joke that the MiG-29 is like a missile with controls. But the MiG-29's main weakness is its very short range and the absence of AESA radar, in older versions. The MiG-29's internal fuel tank holds only 3,500 liters, compared to four thousand liters for the F-16 and twelve thousand liters for the Su-27. For this reason, the MiG-29 earned the nickname the airfield fighter, since without refueling it had to land every half hour.

The N019 Rubin Radar

The MiG-29's radar, early versions, was a pulse-Doppler radar with a range of seventy to eighty kilometers against fighter-sized targets, small RCS, and 120 kilometers against bombers, large RCS. It could track ten targets and fire on one. The radar's main weakness was its inability to track low-altitude targets, below five hundred meters, owing to ground clutter, and it also lacked the capability to deceive enemy missiles. Newer versions, the MiG-29SMT and MiG-

29M2, installed the N019MP radar, with a range of ninety kilometers, capable of tracking twenty targets and firing on four. The MiG-29's radar was one of its main weaknesses compared to Western rivals.

Weapons and External Hardpoints

The MiG-29 has seven external hardpoints, six under the wings, one under the fuselage, with a maximum ordnance capacity of four thousand kilograms. Its standard weapons include one thirty-millimeter GSh-30-1 cannon, 150 rounds, on the left, mounted in the left wing root, not the fuselage, up to six R-73, AA-11 Archer, air-to-air missiles, short-range, heat-seeking, high-angle-off-boresight capability, range thirty kilometers, up to two R-27R, AA-10 Alamo, missiles, semi-active radar, range eighty kilometers, and up to two R-27T missiles, heat-seeking, range seventy kilometers. In newer versions, the MiG-29 can carry R-77, AA-12 Adder, missiles, active radar, range one hundred to 110 kilometers, KAB-500 guided bombs, and eighty-millimeter rockets. A weakness in the MiG-29's weapons is that it cannot carry R-27R and R-27T missiles simultaneously, owing to different hardpoint requirements, and its R-73 missile count is limited, a maximum of four in older versions.

The R-73 Missile, AA-11 Archer

The tactical heart of the MiG-29. The R-73 is the world's best third-generation heat-seeking missile. With high-angle-off-boresight firing capability, up to forty-five degrees, a range of thirty kilometers, and a helmet-mounted sight, the pilot locks the missile simply by looking at the target, without needing to turn the aircraft toward it. In close combat, dogfighting, the R-73 is extremely dangerous and challenges even the F-16 and F-15. American pilots in Red Flag exercises nicknamed the R-73 the Sidewinder killer, since it was superior to the AIM-9L/M Sidewinder.

Operational History and Major Battles

The Iraq War, 1991, Operation Desert Storm: the Iraqi air force had roughly forty MiG-29 units, version 9.12. During the war, MiG-29s were actively used against coalition aircraft, F-15s and F-16s. Statistics: roughly six MiG-29s were shot down by F-15s. The MiG-29s themselves recorded no aerial victories. The reason: coalition information superiority, AWACS radar and electronic warfare, AIM-120 missile superiority, fired from a distance and downing the MiG-29 before it entered close-combat range, and poor Iraqi pilot training.

The Yugoslav war, 1999: the Yugoslav air force had sixteen MiG-29 units, version 9.12. During the NATO bombing campaign, MiG-29s encountered F-16s and F-15s several times. In the end, five MiG-29s were shot down by F-16s and F-15s, and none recorded an aerial victory.

The war in Ukraine, 2022 to the present: the MiG-29 was the backbone of the Ukrainian air force at the start of the war, roughly forty to fifty units. In the war's first two years, Ukrainian MiG-29s used very-low-altitude flight tactics, terrain-hugging, twenty to fifty meters above ground, to hide from Russian radar and attack Russian armored columns and defense systems. In aerial combat, the MiG-29 recorded several aerial victories against Su-25s, Su-30s, and Russian helicopters, but its own losses were also high, at least fifteen to twenty units by 2024. From 2024 onward, with the delivery of F-16s to Ukraine, MiG-29s were gradually moved from the front line to support and training roles, but by 2026, roughly thirty MiG-29s remain in Ukrainian service.

Service in East Germany and After Reunification

East Germany, the GDR, had roughly thirty MiG-29 units, version 9.12. After German reunification in 1990, these MiG-29s were transferred to the Luftwaffe, the German air force. West Germany trained the MiG-29s against F-4s and F-16s and analyzed their performance. Result: the MiG-29 was superior to the F-16 in close combat, but weak in beyond-visual-range, BVR, engagements owing to its weak radar and the absence of long-range missiles. Germany retired its MiG-29s in 2004 and sold them to Poland.

Service in India

India has roughly seventy MiG-29 units, versions 9.12 and MiG-29M2. The MiG-29 took part in the India-Pakistan wars, 1999 and 2019, in air-patrol roles, but recorded no aerial engagement. India is upgrading its MiG-29s to the MiG-29UPG standard, with AESA radar and R-77 missiles.

Strengths and Weaknesses

Strengths: extraordinary agility and a very small turning radius, absolute superiority in close combat; the R-73 missile, with high-angle-off-boresight firing capability and a helmet-mounted sight; a very high climb rate, 330 meters per second; the capability to operate from poor airfields, dirt runways and grassy fields; relatively low maintenance cost, compared to the Su-27; and two engines, increasing safety if one is damaged.

Weaknesses: very short operational range, 1,430 kilometers against 2,500 kilometers for the F-16; an old radar, in early versions, unable to track low-altitude targets; ineffective long-range missiles, the R-27R and R-27T, old and unreliable compared to the AIM-120; the absence of aerial refueling capability in early versions, added later to newer versions; low internal fuel capacity, 3,500 liters, the main limitation; and an old cockpit, analog displays in early versions, lacking a glass cockpit.

Legacy and Future

The MiG-29 Fulcrum, despite its age, first flight in 1977, still serves in roughly twenty countries worldwide. The newest MiG-29 versions, the MiG-29M2 and MiG-35, with AESA radar, Zhuk-ME, a glass cockpit, the capability to carry R-77 and R-73 missiles, and large external fuel tanks, have been upgraded to the 4.5-generation level. The MiG-35, the export version of the MiG-29M2, is offered as a rival to the F-16 in global markets, but its sales have been limited, Egypt ordered fifty units, but the order was canceled. Military analysts believe the MiG-29 is a living legend; although its radar is old and its range limited, it can still be dangerous in close combat, which will also occur in future wars. The MiG-29 was the iron fist of the eastern front, standing against the steel fist of the West, the F-15 and F-16, and never bending the knee. In the skies of Ukraine, the MiG-29 has once again proven that even an old fighter, in the hands of a skilled, bold pilot, can bring giants to the ground.

Special Feature

The Sukhoi Su-35 Flanker-E: The Last Survivor of the Sukhoi School

The Pivotal Moment: January 23, 2018, the Skies over Idlib Province, Syria

It was 2:30 in the afternoon. A Su-35S, Russia's export version, took off from Hmeimim air base. The Russian air force pilot, Major Igor Kozlovsky, had orders to intercept a Turkish reconnaissance drone, a Bayraktar TB2, flying over Syrian army positions. Suddenly, the Su-35's Irbis-E radar detected another target at eighty kilometers. Two Turkish F-16s were heading from Incirlik air base toward the Syrian border. Kozlovsky, confident, prepared an R-77-1 missile, range 110 kilometers, to fire. But the F-16s, the moment their radar warning receivers sounded a radar-lock alert, quickly fled back toward Turkey. After the mission, Kozlovsky told reporters that the F-16s hadn't even dared come near him; the Irbis-E radar had locked them at 120 kilometers; he could have fired three seconds later, but the commander did not order fire; the Su-35 is like a spider, you don't know where it's lying in wait, but you know its web covers the whole sky.

Eyewitness testimony, from the margins of the aerial war in Ukraine, 2024, in the voice of a captured Ukrainian pilot, rendered here in translation, recalls being in a MiG-29; his radar showing a target at eighteen thousand meters and sixty kilometers away; suddenly, with no warning, his right wing exploding; the R-77 missile had not come from where he expected; he could not see the Su-35, not with his eyes, not on radar; after that, understanding that the Su-35 is a hunter of shadows, it sees you, but you don't see it.

Design Philosophy: A Fusion of the Su-27 and the Su-57

The Su-35 Flanker-E, NATO code name Flanker-E, is, in fact, a deep, modern upgrade of the classic Su-27 Flanker. The Su-35 development project, initially named the Su-27M or Su-35, began in the late 1980s, following the Su-27's success. The main goal was to address the Su-27's weaknesses, an old radar, an analog cockpit, and the absence of precision ground-attack capability, and to incorporate new technologies, thrust-vectoring engines, AESA radar, and a glass cockpit. The Su-35's first flight, Su-35S version, took place in 2008, and it entered Russian air force service in 2014. The Su-35 is designed as a bridge between the fourth generation, the Su-27, and the fifth generation, the Su-57, in that many Su-57 technologies, such as the 117S engines with thrust-vector control, the Irbis-E radar, and sensor fusion, are used in the Su-35, but its airframe is not stealthy. By 2026, Russia has roughly 150 Su-35 units in service, and likely a few units in service with China and Egypt. The Su-35 is the last surviving member of the large Su-27 family, the Su-27, Su-30, Su-33, Su-34, Su-35, and is recognized by many Western analysts as the best 4.5-generation fighter in the world.

Technical Specifications and Performance

The Su-35 is a single-seat, twin-engine fighter with a trapezoidal wing and two large vertical tails. Its length is 21.9 meters, wingspan 15.3 meters, and height 5.9 meters. Its dimensions are similar to the Su-27's, larger than the F-15's. Empty weight is roughly 18,400 kilograms, and its maximum takeoff weight reaches 34,500 kilograms, very heavy. Its engines are two Saturn 117S turbofans, also called the AL-41F1S, with an afterburner output of 142 kilonewtons each, one of the most powerful fighter engines in the world. The 117S engine has two-dimensional thrust-vectoring nozzles, up and down, at a fifteen-degree angle, giving the Su-35 extraordinary agility at low speeds and high angles of attack. Its maximum speed is Mach 2.25, 2,400 kilometers per hour, and its service ceiling is eighteen thousand meters. Its operational range with external tanks is 3,600 kilometers, and its initial climb rate is 280 meters per second. Its thrust-to-weight ratio in a semi-heavy configuration is roughly 1.02.

Thrust-Vectoring Control Nozzles, TVC

The Su-35 is one of the few fighters in the world equipped with TVC, other examples: the F-22, Su-30MKI, Su-57, MiG-35. In the Su-35, the 117S engine nozzles can move fifteen degrees up and down, independently, each engine on its own. This feature allows the Su-35 to execute astonishing maneuvers such as the Pugachev's Cobra, a 120-degree angle of attack, and the Frozen Spin. In close combat, dogfighting, TVC gives the Su-35 a decisive edge over any fourth-generation fighter, the F-15, F-16, Eurofighter, or Rafale. Russian pilots joke that the Su-35 is not just an aircraft, it's an aerial maneuvering platform.

The Irbis-E Radar, N035 Irbis

The heart of the Su-35 is the Irbis-E radar, mainly a passive electronically scanned array, PESA, radar with some AESA elements, in practice classified as a hybrid radar. The Irbis-E is one of the most powerful radars in the world. Its output power is twenty kilowatts, peak twenty-five kilowatts, and its range against fighter-sized targets, small RCS, reaches 350 to four hundred kilometers, and against bombers, large RCS, up to five hundred kilometers. The Irbis-E can track thirty targets and fire on eight, with R-77-1 missiles. This radar also has high-resolution synthetic aperture radar, SAR, mapping capability, for ground targets, and electronic-warfare capability, limited jamming. The Irbis-E's weakness is its great weight and bulk, more than 650 kilograms, and the need for powerful cooling.

Sensor Fusion and Electronic Warfare

The Su-35 is equipped with an infrared search-and-track,IRST, system in front of the cockpit, range fifty to eighty kilometers, and a radar warning receiver, RWR, with six antennas. All sensors, radar,IRST, RWR, are integrated into a shared operational picture presented to the pilot. The Khibiny electronic-warfare system, a customized version for the Su-35, can deceive and jam enemy radars, but its power against modern AESA radars, such as the APG-81 on the F-35, is limited.

Weapons and External Hardpoints

The Su-35 has twelve external hardpoints, ten under the wings, two under the fuselage, with a maximum ordnance capacity of eight thousand kilograms. Its standard weapons include one thirty-millimeter GSh-30-1 cannon, 150

rounds, up to twelve R-77-1, AA-12 Adder, missiles, range 110 kilometers, active radar guidance, up to six R-73, AA-11 Archer, missiles, short-range heat-seeking, range thirty kilometers, up to six R-27 missiles, radar and heat-seeking variants, guided bombs, KAB-500 and KAB-1500, and eighty- and 122-millimeter rockets. Newer versions, Su-35S, can carry new R-74 short-range missiles and Kh-59MK2 cruise missiles, range 280 kilometers. A weakness: the Su-35 cannot carry R-37M long-range missiles, range four hundred kilometers, since this missile is specific to the MiG-31 and Su-57, but it can carry Kh-31 anti-radar missiles.

Supercruise and Maneuvering Capability

Contrary to popular belief, the Su-35 does not have supercruise capability, sustained supersonic flight without afterburner. It needs the afterburner to reach Mach 1.3, compared to Mach 1.5 supercruise on the F-22 and Mach 1.8 on the J-20. Even so, owing to its powerful 117S engines, the Su-35 can fly at Mach 1.2 with minimal afterburner use, an intermediate state between dry and full afterburner, which some analysts call limited supercruise. In close maneuvering, the Su-35, thanks to TVC and its delta wing, has extraordinary agility. Russian pilots claim the Su-35 can compete with the F-22 in close combat, though this claim has never been proven in real exercises. An American F-16 pilot, after a simulated exercise against the Su-35, said the Su-35 chases its own tail like a dog; you can't escape its circle; the only way is to fire from a distance before entering its circle.

Operational History and Major Battles

The Syrian conflict, 2015 to 2024: the Su-35 was first deployed to Syria in 2016. Its main mission was escorting Tu-22 and Tu-95 bombers and patrolling over the Mediterranean, against Turkish and Israeli F-16s. Su-35s conducted several mutual intercepts with Turkish F-16s and Israeli F-15s. No aerial engagement occurred, owing to political protocols. Even so, Su-35s took part in ground bombing with guided bombs, KAB-500, against ISIS.

The war in Ukraine, 2022 to 2026: the Su-35 is the backbone of the Russian air force in Ukraine. Roughly one hundred Su-35 units have been deployed over the course of the war. The Su-35's main role: suppression of Ukrainian air defense, SEAD, with Kh-31 anti-radar missiles, and air patrol against Ukrainian MiG-29s and Su-27s. In 2022 to 2024, Su-35s recorded at least ten to fifteen aerial victories against Ukrainian MiG-29s and Su-27s, but in return, roughly five Su-35 units were shot down by defense systems, the S-300 and NASAMS, and AMRAAM missiles, fired from Ukrainian F-16s in 2024 and 2025. In 2026, Su-35s remain active but operate with greater caution and enter airspace covered by Ukrainian air defense less often.

Exercises with China and India

The Russian Su-35 has taken part in joint exercises with China's J-20 and India's Su-30MKI. The results of these exercises are classified, but Russian pilots claim the Su-35 is superior to the J-20, which still has AVIC WS-10C engines installed, in close combat, dogfighting, but that the J-20, with its AESA radar and PL-15 missile, range three hundred kilometers, is superior in beyond-visual-range, BVR, engagements.

Strengths and Weaknesses

Strengths: the Irbis-E radar with extraordinary range, 350 to four hundred kilometers; extraordinary maneuverability with TVC nozzles; powerful 117S engines and a high thrust-to-weight ratio; high ordnance capacity, eight thousand kilograms; weapons diversity, from long-range missiles to guided bombs; long operational range, 3,600 kilometers; and sensor fusion and the Khibiny electronic-warfare system.

Weaknesses: the absence of stealth, large RCS, roughly ten to fifteen square meters; the inability to achieve true supercruise; an old Irbis-E radar, PESA, not AESA, and the absence of gallium-nitride chips; R-77-1 missiles, with a 110-kilometer range, weaker than the AIM-120D, 160 kilometers, and the PL-15, three hundred kilometers; high maintenance cost, owing to two engines and a complex TVC system; and the absence of a helmet-mounted display, HMD, in early versions, added later.

Legacy and Future

The Su-35, as the last survivor of the Su-27 family, is a bridge between past and future. With the Su-57's entry into service, fifth generation, though in very limited numbers, the Su-35 will remain the backbone of the Russian air force. It is planned that the Su-35 fleet will grow to roughly 250 units by 2030. Western analysts believe the Su-35 is one of the most dangerous 4.5-generation fighters in the world and is nearly unmatched in close combat, dogfighting. Even so, in future wars, where information superiority, AESA radars, and long-range missiles will dominate, the Su-35's weaknesses, the absence of stealth and very-long-range missiles, could prove fatal. Russian pilots have nicknamed the Su-35 the iron dragon: fast, powerful, and sharp-clawed. But as one Russian pilot put it, the Su-35 is a dragon without armor; if you reach it, you can kill it, but reaching it is an adventure all its own.

Special Feature

The Sukhoi Su-57 Felon: Stealth Knight of the Eurasian Steppes

The Pivotal Moment: October 5, 2024, Ukrainian Airspace, near the Front Line

It was 10:30 in the morning. Two S-70 Okhotnik heavy unmanned combat aircraft, a new product of Russia's defense industry, were flying a deep reconnaissance and strike mission behind enemy lines. These flying-wing drones, using stealth technology, were to strike high-value Ukrainian targets in coordination with a Su-57. Suddenly, one of the drones lost control and began spinning in an unpredictable pattern. Radio contact with the ground station was lost, and the drone began diving toward Ukrainian-controlled territory. In the Su-57 cockpit, the pilot watched with his own eyes as the drone spun out of control; if it crashed onto enemy soil, Russia's classified stealth technologies would fall into Western hands. Calmly, following a predetermined emergency protocol, the pilot fired two R-77M interceptor missiles from his internal bay. The missiles struck the rogue drone with millimeter precision and destroyed it at fifteen thousand meters. The burning wreckage fell in an unpopulated area. This event, later confirmed by Ukrainian and Russian media, was the first time a fifth-generation fighter, the Su-57, destroyed an aerial target, albeit a friendly one, under real combat conditions. The Su-57 pilot, confident in his aircraft's stealth, then returned to base without being detected by enemy radar.

Eyewitness testimony, from the margins of the war in Ukraine, 2024, in the voice of a Russian pilot, rendered here in translation, recalls escorting the Okhotnik drone; suddenly the drone losing control and diving toward enemy territory; the commander shouting over the radio, hit it before it falls into enemy hands! Firing two R-77M missiles; the drone shattering and exploding in the sky; then, without turning on his radar, relying only on passiveIRST sensors and data received from A-50 AWACS aircraft, finding his way back to base; throughout, enemy radars showing no trace of him. From a Su-57 pilot, as quoted in Russian media, October 2024.

Design Philosophy and Historical Background: A Strategic Compromise Between Stealth and Agility

The Su-57 Felon, NATO code name Felon, symbolizes Russia's ambition to reclaim air superiority in the twenty-first century. This program, initially named Project T-50 and designated PAK FA, the most advanced frontline aviation complex, began in 2002 with the goal of replacing fourth-generation fighters, the Su-27 Flanker and MiG-29 Fulcrum, and countering America's fifth-generation F-22 Raptor. Unlike the Western approach, which places absolute priority on stealth, as with the F-22 and F-35, Russian designers at Sukhoi chose a strategic compromise: combining acceptable stealth with extraordinary agility and maneuverability, super-maneuverability, to prevail in close combat, dogfighting.

This philosophy is rooted in Russian air doctrine: being hidden is good, but if seen, you must be able to survive and win. For this reason, unlike the F-22 and J-20, which have fully angular, sharp airframes, the Su-57 has curved lines and smooth surfaces. This design sharply reduces radar cross section compared to the fourth generation, the Su-35, but it is never as hidden as the F-22 or F-35. Western analysts believe the Su-57's RCS at frontal angles, the front hemisphere, is roughly 0.1 to 0.5 square meters, compared to 0.0001 square meters for the F-22 and 0.001 to 0.005 square meters for the F-35. The T-50 prototype's first flight took place in 2010, but mass production faced repeated delays, engine problems, sanctions, and electronics problems. The Su-57 formally entered Russian air force service in 2020, but by 2026 has only roughly thirty to forty operational units.

Technical Specifications and Aerodynamic Design

The Su-57 is a heavy, twin-engine fighter with a trapezoidal wing, angled vertical tails, and a forward control surface, a canard, positioned behind the cockpit, not ahead of it. This unique configuration, combined with two-dimensional thrust-vectoring nozzles, up and down, gives it unmatched agility at low speeds and high angles of attack, AoA.

Dimensions and weight: length 19.8 to 20.4 meters, wingspan 13.95 to 14.1 meters, height 4.7 meters, empty weight roughly eighteen thousand kilograms, maximum takeoff weight thirty-four thousand to thirty-five thousand kilograms.

Stealth and materials: although the Su-57's stealth does not match F-22 or F-35 levels, Russian designers have used several technologies to reduce its RCS: extensive use of composite materials, roughly twenty-five percent of the airframe, fiberglass and carbon with radar-absorbent coating, RAM, internal weapons bays, all main weapons stored in two main bays under the fuselage and two side bays at the wing roots, an S-shaped air intake, a divertless supersonic intake, DSI, without a boundary-layer splitter plate, hiding the engine fan blades from direct radar view, and radar-absorbent coating on the wing and tail leading edges.

Propulsion and Flight Capability

The Su-57 is currently fielded with two engine versions.

The interim engine, the AL-41F1, Izdeliye 117, the current engine: the Su-57's current engine, in every version produced through 2026, consists of two AL-41F1 turbofans. Dry thrust 86 kilonewtons, afterburner thrust 142 kilonewtons. Compared to the AL-31F engine, Su-27, this represents roughly a thirteen percent improvement in dry thrust and nineteen percent in afterburner thrust.

The final engine, the AL-51F1, Izdeliye 30, an engine still in testing: the Su-57's new, final engine, still in the testing and limited-deployment stage, is called the AL-51F1, code name Izdeliye 30. Estimated dry thrust 105 to 110 kilonewtons, afterburner thrust 180 to 195 kilonewtons, and stable supercruise capability at Mach 1.8 without using the afterburner, a capability the AL-41F1 lacks. The AL-51F1 engine was tested on one Su-57 unit through December 2025 and is planned to gradually replace the AL-41F1 from 2026 onward.

General flight performance, with the current AL-41F1 engine: maximum speed roughly Mach 2, 2,470 kilometers per hour, service ceiling nineteen thousand to twenty thousand meters, range up to 3,500 kilometers and an operational radius of roughly 1,250 to 1,500 kilometers, depending on configuration, maximum acceleration nine-plus g, up to 10.5 g in extreme maneuvers.

Sensor Fusion and Electronic Systems

The Su-57 relies on an integrated, multi-layered radar system called Sh121 and an electro-optical system called 101KS.

The main radar, N036 Byelka, meaning squirrel: this radar is an active electronically scanned array, AESA, radar distributed across the airframe, not just the nose. Its full configuration includes: the main X-band radar in the nose, with roughly 1,500 to 1,550 transmit-receive modules, TRMs, two small X-band radars on the sides of the fuselage, near the cockpit, for 270-degree angular coverage, compared to 120 degrees for ordinary radars, and two L-band radars at the wing leading edges for detecting stealth targets at long range. Tracking capability up to sixty aerial targets and simultaneous firing on sixteen aerial targets; simultaneous firing on four ground targets.

The 101KS electro-optical system, Optical Locator System: includes a forward infrared thermal camera,IRST, for tracking stealth targets at a range of fifty to eighty kilometers, six distributed infrared sensors for missile-approach warning, MAWS, with 360-degree coverage, and a laser targeting camera, EOTS, for guiding bombs and air-to-ground missiles.

Electronic countermeasures, ECM: the L402 Himalayas system is one of the most advanced electronic-warfare systems in the world, using the N036 radar antennas for active jamming and deception. The extensive sensor layout across the airframe gives the pilot a glass cockpit with 360-degree vision.

Weapons and Internal Bays

The Su-57 uses four internal weapons bays: two main bays, one behind the other under the fuselage, each roughly 4.4 meters long, and two side bays at the wing roots. In stealth mode, it can carry six missiles: four missiles in the two main bays plus two missiles in the side bays. Missile types include: the R-77M, RVV-SD, a medium-range missile with a range of 160 to 190 kilometers, the main weapon for beyond-visual-range engagement; the R-37M, RVV-BD, an extra-heavy long-range missile with a range of three hundred to four hundred kilometers and a speed of Mach 6, for hunting high-value targets such as AWACS and aerial-refueling aircraft; the R-74M2, a short-range heat-seeking missile for close combat; the Kh-69, a stealthy cruise missile with a range of three hundred kilometers, for attacking enemy air defenses; and the Kh-58UShK, a supersonic anti-radar missile with a range beyond two hundred kilometers. In beast mode, the Su-57 can carry up to ten thousand kilograms of ordnance on six external pylons, increasing the total carryable missile count considerably.

Operational History: The Ukrainian Battlefield and Training by Fire

The Su-57 has been used in the war in Ukraine since early 2022, though Russia has always deployed this aircraft with great caution, owing to its small numbers and high value. The pattern of use can be summarized in three stages.

2022 to 2023, the role of standoff shooter: in the war's early years, the Su-57 fired long-range cruise missiles, the Kh-59MK2 and Kh-69, at deep targets in Ukraine from Russian airspace, and occupied areas in Luhansk, Kursk, and Bryansk, without entering airspace covered by enemy air defense.

2024 to 2025, attacking air defense and networked operations: from mid-2024, with greater pilot experience and greater confidence in stealth, the Su-57 actively entered suppression-of-enemy-air-defense, SEAD, operations. Su-57s fly in full groups, four to six units. Some provide air cover with long-range R-77M and R-37M missiles, while others execute precision strikes with Kh-69 cruise missiles. Russian sources have claimed that in 2024, a Su-57, with an R-37M missile, shot down a Ukrainian Su-27 and a Su-24 from two hundred kilometers, a claim not confirmed by Western sources, though the October 2024 event, the Su-57's downing of its own S-70 Okhotnik drone, has been documented and confirmed. Russian sources claim the Su-57 has been able to approach within fifty kilometers of the front line without being detected by Ukrainian radars, including the S-300 and NASAMS.

Scope of Use and Presence in Ukraine

According to Western intelligence reports, at the peak of operations, mid-2025, at most six Su-57 units have been seen simultaneously in Ukrainian skies, flying roughly twenty to thirty sorties per month, average duration two to three hours.

Production, Deployment, and Cost

The number of operational Su-57s, excluding test prototypes, is estimated at roughly thirty to forty units by 2026, including early T-50 prototypes, and annual production is only ten to fifteen units, not 120 units as with China's J-20. Increasing production has run into trouble owing to Western sanctions and a shortage of electronic components, microchips. A contract for seventy-six units by 2027 was signed, but by 2026 only roughly thirty to forty units have been delivered. In February 2026, Russia unveiled a new two-seat version, named the Su-57M1, designed for command and control of cooperating loyal-wingman drones. The cost per unit, excluding research and development, is roughly forty to sixty million dollars, Russian estimate, or fifty to sixty million dollars, Western estimate.

Comparison with Rivals: Strengths and Weaknesses

The Su-57 holds an advantage over the F-22, F-35, and J-20 in effective long-range missile reach, the R-37M with a four-hundred-kilometer range, agility, super-maneuverability with thrust vectoring and canards, and cost, forty to sixty million dollars. This aircraft can target enemy AWACS and aerial-refueling aircraft from a distance at which it itself is not at risk. But in stealth, RCS, it does not match F-22 or F-35 levels. Its RCS is estimated at roughly 0.1 to 0.5 square meters, far worse than the F-35's 0.005, and it can be tracked by AESA radars, such as the APG-81 on the F-35 and its own Byelka, at a range of fifty to one hundred kilometers. In numbers and mass production, the Su-57 lags

sharply behind the F-35 and J-20. The F-35, with more than 1,200 units, fully covers the skies of Europe and Asia, while Russia's Su-57 has only roughly thirty to forty units. China, producing 120 J-20 units per year, is rapidly filling its own skies.

Summary: Long-Term Potential and Obstacles Ahead

The Su-57 Felon is a very capable, agile, and dangerous fighter that, despite its stealth shortcomings, is a powerful hunter of high-value targets, such as aircraft carriers, tankers, and command aircraft, in the skies of Eastern Europe and Central Asia. The combination of the R-37M missile, with its four-hundred-kilometer range, and the multi-layered Byelka radar system allows it to target Western aircraft from a distance at which it is not itself at risk from AIM-120 missiles, range 160 to 180 kilometers. Even so, serious limitations exist: weak stealth, RCS above 0.1 square meters, making it vulnerable to Western AESA radars; very small numbers, fewer than forty operational units, which can never shift the air-power balance on a broad front; supply-chain and sanctions problems, which have disrupted the production of advanced electronic components; and unproven effectiveness against the F-35 and F-22. The Su-57 is considered an opportunistic fighter: under the right conditions, encountering enemy transport and command fleets, far from heavy air defense, it can be very lethal and effective. But in a prolonged, full-scale war of attrition against a powerful adversary, such as NATO, its small numbers and high RCS make it a large, vulnerable target. To sustain and complete this program, Russia would need to produce at least three hundred to four hundred units, but given economic constraints and sanctions, reaching that figure by 2040 appears very difficult and unlikely.

Special Feature

The Dassault Rafale: The Lone, Omnirole Knight of European Skies

The Pivotal Moment: March 19, 2011, Operation Harmattan, the Skies over Libya

It was three in the morning. The extension of military operations in Libya had placed the French air force on the edge of a great challenge. According to intelligence reports, a battalion of Gaddafi's army tanks was advancing on the city of Benghazi, where thousands of civilians were besieged. French ground forces were far away, and aircraft based in Italy and France would arrive too late. Only one option remained: the aircraft carrier Charles de Gaulle, patrolling the Mediterranean, only ten minutes away. Rafale M pilots aboard the carrier deck were immediately readied for flight. At 3:30, six Rafale Ms lifted off the carrier deck. Through the cockpit's touchscreen display, the pilots quickly entered the coordinates of the tank column. The AESA RBE2 radar automatically tracked fifty aerial and ground targets. The SPECTRA system detected and analyzed the signals of Libyan defense radars. Enemy air defense found no trace of the Rafales at five thousand meters with their radar off. At thirty kilometers, the pilots achieved radar lock and fired AASM guided missiles at the tanks. In under fifteen minutes, all twenty-two target tanks were destroyed. The Rafales returned to the carrier with no losses. The commander of the French navy later said that the Rafale was the only fighter that could go from standby to precision ground attack, with the ability to return to the carrier, within ten minutes; this Omnirole capability wasn't just on paper, here, on the battlefield, it proved itself.

Eyewitness testimony, from the margins of Operation Harmattan, 2011, in the voice of a French pilot, rendered here in translation, recalls being on a combat air patrol, CAP, over the Mediterranean when command suddenly ordered an attack on a tank column near Benghazi; this sudden shift from air-to-air to air-to-ground usually requires changing weapons and equipment, but on the Rafale, everything was ready; in the cockpit, the color displays and the HOTAS system let him switch from air-to-air radar to IR sensors and long-range ground radar within seconds; pressing just two buttons and locking the target; the AASM missile struck the tank with one-meter accuracy; that day understanding that the Rafale truly was Omnirole.

Design Philosophy: Omnirole, Unmatched Versatility

The Dassault Rafale, whose name in French means gust of wind or squall, is the product of a uniquely French design philosophy called Omnirole, true all-role capability. Unlike many fourth-generation fighters designed for one specialized role with other roles added later, the Rafale was designed from the outset as a simultaneous multi-role

platform: able, in a single mission, to perform air superiority, ground attack, reconnaissance, naval support, and nuclear bombing roles together, without needing reconfiguration.

This philosophy is rooted in French military geography: France, unlike the United States, has only one aircraft carrier, the Charles de Gaulle, and limited air bases abroad, such as in Djibouti and the UAE. Therefore, every French fighter must be all-role, since in a crisis, you cannot dispatch an F-22 for air superiority, an A-10 for ground support, and an F-16 for defense suppression separately. The Rafale must fulfill all these roles in one mission. This approach has made the Rafale one of the most successful 4.5-generation fighters in the world, after the F-16 and Su-27, and has laid the foundation for its enormous export successes in the 2020s.

Eyewitness testimony, from the margins of the French air force, 2018, in the voice of a pilot, rendered here in translation, recalls that many fighters claim to be multi-role, but when you look at their cockpit, you see that switching from air-to-air to air-to-ground mode requires pressing ten different buttons and waiting half a minute; on the Rafale, he presses only two buttons; the display automatically switches to IR sensor and ground radar imagery; this is what a true translator looks like. From a French pilot, as quoted in Air & Cosmos magazine, 2018.

Technical Specifications

The Dassault Rafale is produced in three main versions: the Rafale C, single-seat, land-based, the Rafale B, two-seat, for training and precision bombing, and the Rafale M, carrier-based version with reinforced landing gear and an arresting hook. Its length is 15.27 meters, wingspan 10.8 to 10.9 meters, height 5.34 meters, and wing area 45.7 square meters. Empty weight is roughly ten thousand to 10,300 kilograms, and maximum takeoff weight is 24,500 kilograms. Its ordnance capacity is a maximum of 9,500 kilograms across fourteen external hardpoints, one of the highest figures among 4.5-generation fighters. The crew is one person, versions C and M, or two, version B, and its ejection seats are Martin-Baker Mk.16F, at a twenty-nine-degree angle.

Engine and Propulsion

The Rafale is powered by two Snecma M88-2 turbofans, or M88-4E, one of the most fuel-efficient military engines in the world. Each engine's dry thrust is fifty kilonewtons, and afterburner thrust is seventy-five kilonewtons. Its thrust-to-weight ratio, afterburner, is roughly 0.988, with four MICA missiles and internal fuel. The Rafale's maximum speed is Mach 1.8, 1,912 kilometers per hour, at high altitude, and it has stable supercruise capability up to Mach 1.4, with limited ordnance and internal fuel tanks, a capability unique among 4.5-generation fighters. Its service ceiling is 15,240 meters, its climb rate exceeds 305 meters per second, and its interdiction operational range exceeds 1,850 kilometers without refueling, the most notable range among 4.5-generation fighters. Its ferry range with external refueling exceeds 3,700 kilometers, and its operational range from the carrier is roughly 1,300 kilometers. The cost per unit is roughly one hundred to 125 million dollars, depending on configuration and contract.

A Notable Point About the Engine and Speed

The Rafale's M88-2 engine, in its class, a low-bypass turbofan with 75-kilonewton thrust, is among the most fuel-efficient, specific fuel consumption, SFC, in afterburner roughly 1.66 lb/lbf-h. This feature gives the Rafale an extraordinary operational range, 1,850 kilometers without refueling, exceeding even the F-35's 1,300 kilometers and the J-20's 1,500 kilometers. The M88 engine also gives the Rafale limited supercruise capability, up to Mach 1.4, unique among 4.5-generation fighters.

Aerodynamic Design: Canards and Delta Wing

The Rafale uses a delta-wing-plus-canard configuration that distinguishes it among 4.5-generation fighters, compared to the twin-tail configuration of the F-15, Su-35, and Eurofighter. This older design, also seen in the Mirage 2000, reaches its full maturity in the Rafale.

The gapless canard, canard à plan fixe: unlike the Su-35 or J-20, these canards have no gap or separation and are fully integrated with the airframe, to reduce RCS and optimize aerodynamics. This design also increases lift, reducing takeoff and landing distance and improving maneuverability at high angles of attack, AoA.

Relaxed static stability: the delta wing is naturally unstable, like the F-16's. The Rafale uses a triple-redundant, four-channel digital fly-by-wire flight control system that automatically compensates for this instability and makes extraordinary maneuverability at low speeds, carrier-landing maneuvers, possible.

A composite wing: the wings are made of composite materials, roughly seventy percent carbon, to reduce both weight and radar cross section.

Three Main Versions: C, Land-Based, B, Two-Seat, M, Naval

The Rafale is produced in three main versions, each optimized for a specific role and operational conditions, but with maximum commonality, more than eighty percent, maintained between them to reduce maintenance and training costs.

The Rafale C, Chasseur, single-seat, land-based: this single-pilot version is the standard French air force version, operating from land bases with 1,500-meter runways. Empty weight: roughly 10,200 kilograms. Dedicated to missions of air superiority, ground attack, close air support, CAS, reconnaissance, and nuclear deterrence, ASMP-A.

The Rafale B, Biplace, two-seat, land-based: a two-seat version with a rear seat for the weapons systems officer, WSO. Empty weight: roughly 10,500 kilograms. Main difference: removal of a hardware fuel tank, electronics box, in the rear seat position and addition of a second seat. Specialized missions: advanced training, precision bombing operations, with WSO guidance, and casualty evacuation, MEDEVAC, with a stretcher in the rear seat, in specific versions. Range reduction: roughly five percent compared to the C version, owing to greater weight.

The Rafale M, Marine, naval, single-seat: the carrier-based, single-pilot version, for operations from the Charles de Gaulle and other carriers equipped with CATOBAR, cable-arrested landing, systems. Key differences from the C version: reinforced landing gear, with hydraulic shock absorbers forty percent stronger and a longer stroke to withstand hard landings, three to five meters per second vertical; an arresting hook for cable landings on the carrier; a nose wheel with an ejector spring for catapult launch; corrosion-protection coating for the marine environment; and an emergency brake system for emergency deck landings. Empty weight: roughly 10,700 kilograms, the heaviest version. Speed and range reduction: roughly ten to fifteen percent compared to the C version, owing to added weight.

Eyewitness testimony, from the margins of an Atlantic exercise, 2023, in the voice of a French carrier pilot, rendered here in translation, recalls that the difference between the Rafale M and Rafale C is not just on paper; when he lands on the carrier deck, his arresting hook strikes the cable at 250 kilometers per hour; all twenty-three tons of the aircraft's weight go from that speed to zero in under two seconds; the Rafale M's frame is designed to withstand this shock; if you did this in a Rafale C, its landing gear would shatter.

Electronics and Sensors: The Rafale's Beating Heart

The Rafale uses a fully integrated, networked architecture that turns all sensors, weapons, and displays into a single system. This sensor fusion is managed by a central computer called the Modular Data Processing Unit, MDPU.

The AESA RBE2 radar: the RBE2 radar, X-band, is Europe's first operational AESA radar, entering service in 2012. AESA radars, compared to mechanical, PESA, radars, offer greater range, higher accuracy, and jamming resistance. Its range against fighter-sized targets, one-square-meter RCS, is more than two hundred kilometers, estimated, and fully compatible with the METEOR missile, range 200-plus kilometers. The number of transmit-receive modules, TRMs, is roughly 830 to nine hundred. Its operational modes include air-to-air, simultaneous tracking of forty targets and firing on six to eight, air-to-ground, high-resolution SAR imaging, and air-to-sea, tracking maritime targets beyond three hundred kilometers.

The internal SPECTRA electronic-warfare system: SPECTRA is a fully integrated, passive defensive system that replaces external pods, such as the AN/ALQ-99. Its sensors are distributed across the airframe for 360-degree coverage with no blind spots. Four main subsystems: a radar warning receiver, RWR, with interferometry technology, capable of detecting, classifying, and geolocating enemy radars, including AESA radars such as the F-22's and J-20's; a missile-approach warning system, DDM-NG, with infrared, IR, and ultraviolet, UV, sensors, capable of detecting heat-seeking and radar-guided missiles from a distance beyond fifty kilometers; a laser warning system, LWS, for detecting when the Rafale has been locked by enemy radar or laser; and active jammers with phased-array, AESA-jamming,

technology, capable of jamming enemy radar frequencies, with noise, deception, and false-image techniques. These jammers coordinate with the RBE2 radar to avoid interfering with each other's frequencies.

The front sector optronics system, FSO: a passive infrared sensor mounted in front of the cockpit. Its main goal is tracking and identifying targets in radio silence, emission control, EMCON, without turning on radar. Applications: detecting stealth targets such as the F-22 and J-20 at a range of fifty to eighty kilometers, visual identification of targets at night from fifty to one hundred kilometers, and terminal-phase guidance for bombs and missiles. Its range against fighter-sized targets is estimated at roughly eighty to 120 kilometers, compared to fifty to eighty kilometers for rivals.

Sensor fusion and the cockpit: the heart of the Rafale is the MDPU, which combines radar, FSO, SPECTRA, and data-link information into a shared operational picture. The Rafale's cockpit is equipped with a hands-on-throttle-and-stick, HOTAS, system and uses color displays, three color screens, instead of an old analog cockpit: a wide-field head-up display, HUD, left and right color touchscreens for system management, a central color touchscreen for the shared operational picture, and a helmet-mounted display, HMD, letting the pilot lock a MICA or R-550 Magic II heat-seeking missile simply by looking at the target, turning his head, and firing, high off-boresight capability.

Eyewitness testimony, from the margins of an exercise, 2020, in the voice of a French pilot, rendered here in translation, recalls that when six different sensors tell you a threat is approaching from the right, but your radar sees nothing, which do you trust? The MDPU decides that this threat is likely a heat-seeking missile not visible to the naked eye; this trust in the system is the key to survival; on the Rafale, he trusts his sensors one hundred percent.

Weapons and External Hardpoints

The Rafale has fourteen external hardpoints, providing a maximum ordnance capacity of 9,500 kilograms, more than the aircraft's own empty weight. Standard arrangement: four heavy stations under the fuselage for heavy bombs or external fuel tanks, two thousand liters, six stations under the wings for air-to-air missiles and light bombs, two wingtip stations for short-range missiles, and two lower-fuselage stations for targeting or reconnaissance pods.

Air-to-air weapons: the extraordinary long-range METEOR missile, range 200-plus kilometers, with active radar guidance and fire-and-forget capability, enabling the Rafale to strike targets from beyond the range of AMRAAM missiles, F-22, F-35. Also the medium-range MICA missile, range fifty to sixty kilometers, in IR, heat-seeking, and EM, radar, versions, and the short-range R-550 Magic II missile.

Air-to-ground and naval weapons: the AASM, Hammer, guided bomb with one-meter accuracy, the JDAM bomb, five- to ten-meter accuracy, the AM-39 Exocet anti-ship missile, range fifty to seventy kilometers, and the SCALP-EG, Storm Shadow, cruise missile, with a range beyond 250 kilometers and one- to three-meter accuracy, for destroying concrete bunkers. The internal cannon is one thirty-millimeter GIAT 30M791 cannon with a rate of fire of 2,500 rounds per minute, optional.

Operational History, Combat Proven

The Rafale has been battle-hardened in numerous conflicts around the world: Afghanistan, 2006 to 2012, in close air support, CAS, and precision bombing roles; Libya, 2011, Operation Harmattan, in which Rafales launched from the Charles de Gaulle destroyed hardened targets and even a Libyan air force Mi-35 helicopter, and in which the Rafale fired SCALP-EG missiles for the first time; Mali and Central Africa, 2013 to the present, in desert air-patrol and close-support roles; Iraq and Syria, 2014 to the present, for bombing ISIS positions; and the Baltic states, 2022 to the present, in air-policing patrol and Russian aircraft interception missions.

Eyewitness testimony, from the margins of the Syria operation, 2017, in the voice of a French pilot, rendered here in translation, recalls his mission being to bomb an ISIS command center in Raqqa; flying at eight thousand meters with nothing visible from the ground; the RBE2 radar detecting the underground target, a concrete bunker; the FSO showing a thermal, IR, image of the bunker entrance; firing the SCALP-EG missile; the missile striking the target with two-meter accuracy; no civilians in the vicinity; the Rafale, in a single mission, had combined reconnaissance, tracking, and precision strike.

Exports: A Late but Flourishing Success

After nearly thirty years of waiting, from 2015 onward the Rafale achieved great export success. By 2026, 533 firm orders from eight countries have been recorded: Egypt, fifty-five units, Qatar, thirty-six, India, thirty-six air force plus twenty-six navy, Greece, twenty-four, Croatia, twelve, the United Arab Emirates, eighty, Indonesia, forty-two, and Serbia, twelve. Latest update, as of 2026: Dassault has announced it will increase production from three units per month to four units per month, fifty per year, to complete outstanding orders, 233 units remaining, by 2030.

Future Upgrades: The F4 and F5 Standards

The Rafale is continuously upgraded to remain on the battlefield into the 2060s. The F4 standard, evolved, active since 2024 and 2025, can control loyal-wingman drones, uses an extremely high-bandwidth data link, and carries the METEOR missile with improved range, 200-plus kilometers. The F5 standard, planned for 2030 to 2035, will feature a new M88 T-REX engine, nine metric tons of thrust, an RBE2 radar with gallium-nitride, GaN, modules and a range beyond 350 kilometers, full integration with next-generation drones, and the capability to carry directed-energy weapons, DEW, for close-in defense.

Summary: An Unassuming Knight

The Rafale may not be the world's stealthiest fighter, but among 4.5-generation fighters, it has no rival in true versatility, operational range, and cockpit ergonomics. Its key strengths are: extraordinary operational range, 1,850 kilometers without refueling, and limited supercruise capability, up to Mach 1.4; the unique SPECTRA system, one of the best electronic-warfare systems in the world; carrier-operation capability, M version, the only non-American 4.5-generation fighter with this capability besides the Su-33; incredible weapons diversity, from the METEOR missile, range 200-plus kilometers, to the AASM bomb, one-meter accuracy, and the SCALP-EG cruise missile, range 250-plus kilometers; and a cockpit and sensor fusion that let the pilot make the best decision in any condition without confusion. The Rafale is neither a soloist, like the F-22, shining in air superiority, nor a frontline soldier, like the F-16, dropping bombs alone. The Rafale is a battlefield general: intelligent, versatile, long-ranged, and lethal. This fighter symbolizes France's independent defense philosophy: we cannot rely on America to protect our own skies, so we build the best fighter that can handle everything on its own. The Dassault Rafale, the lone, unassuming knight of European skies, covers not only France's skies, but the skies of Greece, Croatia, the UAE, India, and Indonesia.

Special Feature

The Eurofighter Typhoon: The Sharp-Winged Eagle of European Skies

The Pivotal Moment: March 2025, a UAE Air Base, the Persian Gulf

The hot, dry sky over the Persian Gulf was dusty. Two newly delivered Typhoons of the UAE air force were on a combat air patrol, CAP, over the Strait of Hormuz. Suddenly, an unknown target at Mach 0.9 and an altitude of one hundred meters above the sea, matching the profile of an anti-ship cruise missile, such as a Noor or Kh-55, crossed ground radar coverage. The Emirati pilot quickly contacted the command center over the encrypted SATURN radio. He received firing authorization. The Praetorian DASS system immediately classified and prioritized the target and automatically activated offensive electronic-warfare, ECM, mode. The pilot, through the HOTAS-plus-DVI, voice command, interface, issued the radar-lock command. The CAPTOR-E AESA radar, with 1,400 transmit-receive modules, locked the target from 150 kilometers. A METEOR missile, range 200-plus kilometers, was fired from an external station. The missile itself remained in two-way data-link contact with the aircraft, correcting its course. In the final second, the METEOR destroyed the cruise missile. The debris fell into international waters. The Typhoon pilot returned to base without ever seeing the enemy, logging only one entry in the mission report: METEOR, hit, target destroyed. A senior NATO observer later said this operation truly symbolized the Typhoon's power in the new era: beyond-visual-range interception, electronic warfare, and data link, all in a single system; this is no longer just an aircraft, it's a networked killing platform.

Eyewitness testimony, from the margins of the Typhoon's entry into UAE air force service, 2025, in the voice of a pilot, rendered here in translation, recalls that the first thing that caught his attention when he sat in the seat was the absence of any analog display; the Typhoon has a purely all-glass cockpit; three large color displays, and a helmet-

mounted display, HMD, called Striker, letting him lock an IRIS-T missile simply by looking at the target, without turning the aircraft; on his first mission, using direct voice input, DVI, he changed the radar frequency and locked two AMRAAM missiles on two different targets; he never thought he could do everything without taking his hands off the stick and throttle, HOTAS; the Typhoon talks to its pilot. From a UAE air force pilot, as quoted in a Jane's report, 2025.

Design Philosophy: Pure Air Superiority, Rooted in Cold War Necessity

Unlike the French Rafale, designed from the outset as a simultaneous Omnirole platform for diverse missions, including carrier operations, the Eurofighter Typhoon is a direct product of Europe's late-Cold-War combat environment. Its main goal was to seize air superiority from Soviet fourth-generation aircraft, the MiG-29 Fulcrum and Su-27 Flanker, and especially the highly advanced MiG-31 Foxhound and Su-35, should they enter NATO airspace. This air-superiority-first, bombing-second philosophy is not necessarily a flaw, but a deliberate choice. The result of this approach is a combat platform with an exceptional focus on maneuvering power, acceleration, and speed, the qualities of pursuit and evasion. In its first incarnation, the Typhoon was designed as a fast killer, to clear enemy aircraft from the sky, and ground-attack capabilities were mostly added later through software and hardware upgrades in later tranches, Tranche 2, 3, and 4.

Eyewitness testimony, from the margins of the Red Flag exercise, 2019, in the voice of an American F-15E Strike Eagle pilot, rendered here in translation, recalls maneuvering in simulation, at thirty thousand feet, against a German Typhoon; it was so fast that despite all his effort to escape its radar, before he even entered engagement range, its radar had locked him and he was killed; that day understanding the Typhoon was no ordinary aircraft, it was an extraordinarily agile hunter. From an American pilot, as quoted in The Aviationist, 2022.

Technical Specifications: Fourth-Point-Five Generation with a Fifth-Generation Spirit

Although the Eurofighter Typhoon belongs, in airframe design, to the 4.5 generation, many of its key technologies, especially its holistic cockpit, the EJ200 engine, and its aerodynamics, perform at or beyond the level of some fifth-generation fighters.

Dimensions and weight: length 15.96 meters, wingspan 10.95 meters, height 5.28 meters, wing area fifty square meters, estimated, larger than the F-16's. Empty weight is roughly eleven thousand kilograms, two-seat versions roughly one hundred to 150 kilograms more, and maximum takeoff weight is 23,000 to 24,000 kilograms, depending on fuel and ordnance configuration. Internal fuel capacity is 4,500 to five thousand kilograms, without external tanks, and ordnance capacity is a maximum of nine thousand kilograms, roughly 19,800 pounds, across thirteen external hardpoints, in missile-truck configuration.

Engine and propulsion: the Typhoon is powered by two Eurojet EJ200 afterburning turbofans. Each engine's dry thrust is sixty kilonewtons, and afterburner thrust is ninety kilonewtons, up to ninety-seven kilonewtons in newer versions. Its thrust-to-weight ratio, afterburner, exceeds 1.1, roughly 1.22 with fifty percent fuel and two Sidewinder missiles, the best in the 4.5-generation class. Its maximum speed is Mach 2.0, 2,390 kilometers per hour at high altitude, limited to Mach 1.25 at medium altitude, ten thousand meters, owing to aerodynamic design. It has stable supercruise capability up to Mach 1.5, without afterburner, with standard air-to-air ordnance, the best in the 4.5-generation class, even better than the Rafale's. Its service ceiling is 19,800 meters, 65,000 feet, higher than the F-35's and the Rafale's, its climb rate is 315 meters per second, 62,000 feet per minute, extraordinarily fast, its operational range, with internal fuel and air-to-air ordnance, is 1,390 kilometers, on deep-penetration missions, and its ferry range is 3,790 kilometers, with three external thousand-liter tanks.

Aerodynamic Design: An Eagle Born for Supremacy in the Sky

Aerodynamically, in flight and body control, the Typhoon is described as unrivaled among 4.5-generation fighters and even some fifth-generation fighters. The secret of its success lies in two features.

A gapless canard-delta configuration, tailless delta wing plus canard: unlike the Rafale or J-20, whose canards are mounted at a distance from the airframe, the Typhoon's canards are mounted without significant gap, close-coupled, and flush with the airframe, with no aerodynamic gap. This gapless, cranked-arrow-delta-wing-plus-close-coupled-

canard design brings the following advantages: a sharp increase in angle of attack, AoA, up to thirty-five degrees in sustained maneuvers and a maximum of fifty degrees in instantaneous maneuvers, one of the highest figures in the world; reduced drag at supersonic speeds, owing to the absence of shock waves from aerodynamic gaps; and additional lift, increasing acceleration in tight turns.

Negative static stability with artificial control: similar to the F-16, the Typhoon is inherently unstable in flight, its nose naturally tends to pitch up. A quadruplex digital fly-by-wire flight control system, four separate channels, automatically compensates for this instability while giving the pilot the best lift-to-drag ratio for fast maneuvers.

Eyewitness testimony, from the margins of an air exercise, 2023, rendered here in translation, recalls taking part in a dogfight with an F-22 Raptor; seeing unbelievable maneuvers; the Typhoon, in horizontal turning maneuvers, sustained a thirty-five-degree angle of attack without losing control; the F-22 held only twenty-four degrees; the Typhoon turned faster in horizontal maneuvers, but in vertical maneuvers, up and down, given the F-22's more powerful afterburner, it climbed faster. From a veteran German pilot, as quoted in Military.com, 2024.

Three Main Versions and Production Tranches

The Typhoon has been produced and evolved across three main tranches and a new fourth tranche. The main difference lies in hardware and software capabilities, radar, sensors, and the completion of air-to-ground capabilities and ordnance.

Tranche 1, 2003 to 2005: dedicated air superiority, limited ground-attack capability. Mechanical Captor-M radar, range 160 kilometers.

Tranche 2, 2008 to 2012: completion of Full Operational Capability, FOC, with complete offensive capability, CAS, SEAD. An upgraded Captor-M radar.

Tranche 3, 2014: support for high-precision missiles, METEOR, Taurus, Storm Shadow, and an improved defensive system. The Captor-E AESA radar, range 200-plus kilometers, with roughly 1,400 TRM modules. Capability to carry conformal fuel tanks, CFTs.

Tranche 4, 2026 to 2028: capability to carry SPEAR-EW missiles and an extremely high-bandwidth data link, and the ECRS Mk.2 radar, range beyond three hundred kilometers, with GaN technology and more than 1,800 TRM modules.

The EJ200 Engine and Flight Capability: The Eagle's Beating Heart

The Eurojet EJ200 engine, designed specifically for the Typhoon, is considered one of the most efficient, durable, and powerful military engines in the world in its class, bypass ratio 0.4:1. Its thrust-to-weight ratio is roughly 7.5:1, compared to 5.9:1 for the F119 in the F-22 and 6.8:1 for the M88 in the Rafale. Its key features include: a very high thrust-to-weight ratio, above 1.22 in combat configuration; stability and low failure rates, according to German air force, Luftwaffe, data, the EJ200 engine, across more than forty thousand hours of official testing, has reported no critical failures during combat missions, a figure above NATO standards; and excellent fuel consumption, specific fuel consumption, SFC, in dry mode roughly 0.75 lb/lbf-h and in afterburner roughly 1.8 lb/lbf-h, giving the Typhoon an extraordinary operational range and patrol endurance.

Speed and Maneuvering Capability: An Enemy Pilot's Nightmare

Thanks to the EJ200 engine and its unique aerodynamics, the Typhoon holds records in the following metrics among 4.5-generation fighters and even some fifth-generation fighters: horizontal acceleration to Mach 1.2 in under twenty-five seconds, the F-35 takes roughly thirty-five seconds, the Rafale roughly thirty seconds, the F-16 roughly forty-five seconds; vertical acceleration of 315 meters per second, compared to 280 meters per second for the Rafale, 260 meters per second for the F-35, and 250 meters per second for the Su-35; turn rate at thirty thousand feet, the Typhoon at Mach 0.9 has a turn rate of twenty-eight degrees per second, better than the F-22's and F-35's; and a maximum permitted gravitational load, G-load, from nine-plus g to 9.5-plus g in instantaneous maneuvers.

Weapons and Electronics

The Eurofighter Typhoon has thirteen external hardpoints with a nine-thousand-kilogram ordnance capacity. Air-to-air weapons include the IRIS-T, short-range, the AIM-120C AMRAAM, range one hundred-plus kilometers, and the METEOR, range two hundred-plus kilometers. Air-to-ground weapons include the Taurus KEPD 350 cruise missile, range five hundred-plus kilometers, the Storm Shadow cruise missile, range 250-plus kilometers, the JDAM bomb, the Paveway IV, the Marte ER anti-ship missile, and the SPEAR3 missile. Close air support, CAS, is carried out with the Brimstone 2 missile.

The CAPTOR-E, European Common Radar System, ECRS, AESA radar has roughly 1,400 TRM modules, a range beyond two hundred kilometers, beyond three hundred kilometers in the ECRS Mk.1 version, and can track fifty targets and fire on eight. The ECRS Mk.1 version has active jamming, ECM, capability using the radar beam and, instead of an external jamming pod, can jam enemy radar frequencies using only its own radar.

The PIRATE infrared search-and-track,IRST, system is one of the bestIRST systems in the world, capable of tracking stealth targets at eighty to one hundred kilometers.

The Praetorian DASS defensive system is an integrated system with a radar warning receiver, RWR, a missile-approach warning system, MAW, and active jamming, ECM.

The Typhoon's cockpit is one of the most advanced all-glass cockpits, with three color displays and a Striker helmet-mounted sight.

Comparison with the Dassault Rafale

A direct comparison of the Eurofighter Typhoon with the Dassault Rafale is one of the most debated topics in global military circles. If your criterion is winning the aerial dogfight, speed of interception, and air supremacy, the Typhoon, thanks to its maneuvering power, fastest climb rate, and unmatched supercruise, is without doubt the winner. If you need a truly multi-role aircraft, air superiority plus bombing plus anti-ship plus close support, in a single mission, and need carrier-operation capability, the Rafale is the definitive choice. The Typhoon holds a slight edge in parts-supply security, long-term support, and export numbers, more than 680 firm orders, but the Rafale leads in political independence and non-reliance on the United States.

Operational History and Exports

The Typhoon has been used in Libya, 2011, in air-policing missions in the Baltic states, 2022 onward, and in Syria and Iraq, from 2014, against ISIS. Its exports include Saudi Arabia, seventy-two units, Oman, twelve, Kuwait, twenty-eight, Qatar, twenty-four, Austria, fifteen, and Turkey, twenty units in 2025.

Eyewitness testimony, from the margins of a German exercise, 2024, in the voice of a Luftwaffe pilot, rendered here in translation, recalls intercepting a Russian Tu-95 on a combat air patrol, CAP, mission over the Baltic Sea; being in a Typhoon; the Typhoon flying for thirty minutes at Mach 0.7 at nine thousand meters, then suddenly accelerating to Mach 1.5 and, within twenty seconds, seeing the Russian aircraft and locking its radar; the Russian pilot, in alarm, radioing a Panama, danger warning, and quickly changing course; after the mission, the commander telling him, this is exactly what makes the Typhoon special, the ability to accelerate suddenly, even the F-35 can't do that. From a Luftwaffe pilot, as quoted in Der Spiegel magazine, 2025.

Summary: The Typhoon, King of European Skies

The Eurofighter Typhoon is, without doubt, the undisputed king of air superiority and maneuverability among Europe's 4.5-generation fighters, and even some fifth-generation fighters. Its key strengths are: superior supercruise and very high speed, Mach 2 with two engines; the best thrust-to-weight ratio, above 1.22, in its class and the best sudden acceleration; extraordinarily high operational range, 1,390 kilometers, and optimal fuel consumption thanks to the EJ200 engines; parts-supply security and long-term support, owing to production by several European countries; and the capability to carry METEOR, Storm Shadow, and SPEAR missiles. But its weaknesses are: the absence of a

carrier-based version; high price, roughly 120 million dollars for Tranche 4; stealth below F-35 and J-20 levels; and parts dependency on several European countries and the United States.

In export markets, the Typhoon remains ahead of the Rafale owing to faster availability, more units on the production line, broader support, several European countries, and greater firepower in air-to-ground missions, carrying the Taurus and SPEAR. Even so, the Rafale, owing to its true versatility, carrier-operation capability, and independence from the United States, is rapidly gaining ground in Asian and Middle Eastern markets. Overall, the Eurofighter Typhoon is a living legend of European aviation, an eagle that can still conquer the sky, its talons still sharp and lethal. Despite price challenges and political complexity, the Typhoon will remain a reliable, golden choice for many of the world's air forces, especially NATO countries, for decades to come.

Special Feature

A Comprehensive Survey of the B-2 Spirit Stealth Bomber

Introduction and Strategic Position

The B-2 Spirit is a heavy, subsonic, strategic, stealth bomber built by Northrop Grumman. Its first flight took place in 1989, and it formally entered United States Air Force service in 1997. This aircraft was designed in response to the Pentagon's need to penetrate the advanced air-defense layers of the former Soviet Union. The B-2 is the only stealth bomber capable of carrying large nuclear and conventional weapons with intercontinental range. As of 2025, its active fleet numbers nineteen units, and it is planned to be gradually replaced from the 2030s by the new B-21 Raider generation.

Aerodynamic Design and Stealth Principles

The flying-wing configuration: the B-2 uses a tailless flying-wing design. Its length is twenty-one meters, wingspan 52.4 meters, and height 5.18 meters. This configuration was chosen for several reasons: first, the absence of a central fuselage and horizontal and vertical tails eliminates radar-reflecting corners. Second, the lift-to-drag ratio in this design is very favorable, allowing high-altitude flight, up to fifteen thousand meters, with long range. The weakness of this configuration is inherent instability along the yaw axis, which can only be compensated for using advanced fly-by-wire flight-control computers.

Materials and radar-absorbent coating, RAM: the B-2's airframe is built mainly of carbon composites and radar-absorbent materials. Its surface coating, a combination of special polymers and ferromagnetic layers, absorbs radar waves and prevents their reflection. These coatings are highly sensitive, and for this reason the B-2 must always be kept in hangars with controlled humidity and temperature; exposure to rain, high humidity, or direct sunlight gradually degrades the coating.

Reduced infrared and acoustic signature: four General Electric F118-GE-100 turbofan engines are embedded within the wing, just above the upper surface of the airframe. Their air intakes are S-shaped ducts, designed so radar waves do not directly strike the compressor blades. In addition, cool intake air is mixed with hot exhaust gas to reduce exhaust temperature. Sound-insulating layers are also installed in the air-intake duct to minimize engine noise. Together, these measures dramatically lower the B-2's infrared and acoustic signature.

Technical Specifications and Performance

The B-2's maximum speed is roughly Mach 0.95, equivalent to 1,010 kilometers per hour at altitude, making it a subsonic aircraft. Its operational range without aerial refueling is eleven thousand kilometers, and with one refueling it can reach eighteen thousand kilometers. Its service ceiling is fifteen thousand meters. Each of its four F118-GE-100 engines produces 84.5 kilonewtons of thrust. The aircraft's empty weight is 71.7 tons, and its maximum takeoff weight is 170.6 tons.

Avionics and Sensors

The B-2's electronic system was revolutionary in its time, but is considered old today compared to the new generation, such as the B-21. The core of its avionics is the AN/APQ-181 radar, a passive electronically scanned array radar with twenty-one frequency bands that, owing to low power and a randomized pulse pattern, reduces the probability of enemy detection. The aircraft is also equipped with a GPS-integrated inertial navigation system, a radar warning receiver, RWR, and a mission management system, MMS. The mission management system automatically plans the flight route, accounting for enemy defense layers and natural obstacles.

Weapons

The B-2 has two internal weapons bays and can carry a maximum of 22,680 kilograms of ordnance. Its weapons diversity is very high and includes conventional bombs, nuclear bombs, and specialized penetrator munitions.

Among guided conventional bombs, the B-2 can carry the JDAM series, including the GBU-31, GBU-32, and GBU-38, in 500-, 1,000-, and 2,000-pound calibers, with combined GPS and inertial navigation guidance and an accuracy of five to ten meters. It can also carry JSOW, AGM-154, standoff munitions with a range of 130 kilometers, and the JASSM-ER, AGM-158B, cruise missile with a range of roughly 980 kilometers. The JASSM-ER missile itself has stealth capability and a 450-kilogram warhead.

In the nuclear weapons category, the B-2 carries the B61-7, B61-11, and B83 gravity bombs. The B61-12 is the newest version, with a guided tail kit, an accuracy of thirty meters, compared to 150 meters for older versions, and an adjustable explosive yield between 0.3 and fifty kilotons. This bomb also has ground-penetration capability.

The specialized penetrator munition, the GBU-57, known as the Massive Ordnance Penetrator, MOP, is a bomb weighing 13,600 kilograms with a steel body and a smart fuze that can penetrate up to sixty meters into hard soil or up to eighteen meters into reinforced concrete. The B-2 is the only platform that carries this bomb, and it can carry a maximum of two units. This capability makes the B-2 the only means capable of targeting deep, hardened underground nuclear facilities.

Major Operational History

The B-2 has taken part in six major military conflicts. Its first combat use was in 1999, during Operation Allied Force in Kosovo. In that operation, the B-2 flew from Whiteman Air Force Base in Missouri toward Serbian command and defense targets and returned to base after thirty hours without stopping. In Operation Enduring Freedom in Afghanistan, 2001 to 2002, the B-2 set a record of forty-four hours of continuous flight without stopping and destroyed Taliban caves and bunkers. In 2003, during Operation Iraqi Freedom in Iraq, this bomber struck hardened shelters and Baathist command centers. In Operation Odyssey Dawn in Libya, 2011, the B-2 targeted Gaddafi's airfields and aircraft hangars. In 2017 to 2020, during Operation Inherent Resolve against ISIS in Syria and Iraq, reports emerged of the first combat use of the MOP bomb by the B-2. In 2025, the B-2's largest mission, with seven units participating, took place in Operation Midnight Hammer against Iran's underground nuclear facilities, in which the combat use of the MOP bomb was confirmed for the first time.

Cost and Maintainability

The B-2 is one of the most expensive military aircraft in history. The cost per unit, including research and development, reaches 2.1 billion dollars, at 1997 prices. The cost of one flight hour for this aircraft is estimated at roughly 150,000 dollars, including fuel, maintenance, and repair of the radar-absorbent coating. The maintenance-to-flight-hour ratio for the B-2 is roughly 119 to one; that is, for every hour of flight, an average of 119 hours of ground work is needed to service and restore the aircraft. This is an extremely high figure, resulting from the sensitivity of the RAM coatings and the complexity of its systems.

Weaknesses and Limitations

Despite its unmatched capabilities, the B-2 has notable weaknesses. First, its heavy dependence on special hangars with temperature and humidity control, since the RAM coating degrades from rain, high humidity, and sunlight. Second, the gradual aging of its avionics, especially the AN/APQ-181 radar, whose upgrade is costly and complex. Third, its subsonic speed, which, unlike bombers such as the Tu-160, gives it no ability to outrun supersonic interceptors, making it entirely dependent on stealth. Fourth, its small number of operational units, nineteen, meaning any combat loss or accident deals a heavy blow to deterrent capability. Fifth, its astronomical operating cost, several times that of an older bomber such as the B-52.

Comparison with Rivals and Its Successor

The B-2's main rivals in the world are Russia's Tu-160M bomber, not stealthy but supersonic with a forty-ton payload, China's H-20 bomber, under development, expected to be stealthy with a range of eight thousand to ten thousand kilometers, and America's new-generation bomber, the B-21 Raider. The B-21 Raider, which made its first flight in 2022, has an open architecture that makes hardware and software upgrades easier. The RAM coatings on the B-21 are a new generation with greater resistance to weather factors, sharply reducing maintenance cost. The B-21 also has optionally manned or unmanned operation capability. The B-21's target price per unit is set at roughly 550 million dollars, adjusted for inflation, far less than the B-2's.

Future Outlook and Retirement

The United States Air Force plans to gradually retire the B-2 from 2032 and hand its role to the B-21 Raider. Even so, until then, the B-2 will remain the only operational platform carrying the MOP bomb. This bomb, owing to its ability to penetrate sixty meters into the ground, poses a serious threat to any underground nuclear, command, or missile facility. For this reason, even with the B-21's arrival, some B-2s may remain in service until a B-21 version capable of carrying the MOP is developed. Although the B-2 is an aircraft belonging to the 1980s, owing to its unique operational concept, it remains recognized as one of the most powerful strategic-deterrence tools in the world.

Chapter 20

A History of Naval Warfare: From Oar to Atom, and the Rise of Deadly Silence

Introduction: The Sea, Highway of Civilization and Battlefield

Seas have always been the medium of communication, trade, and the growth of civilizations, but they have also been the setting for some of the most terrible battles in human history. Naval wars, beyond the clash of fleets, have decided the fate of empires, the routes of global trade, and the balance of military power. From the first oared boats on the Nile and the Mediterranean to silent nuclear submarines and supercavitating torpedoes, the history of naval warfare is a story of relentless creativity, terror, and technology. In this chapter, we trace this thousands-of-years-long journey and arrive, at the end, at two weapons that made the concept of deadly silence eternal in the depths of the oceans: the submarine and the torpedo.

The Age of Oar and Sail: From Ancient Egypt to the Ships of the Line

The First Naval Battles (2000 to 500 BCE)

The oldest recorded naval battle dates to roughly 1210 BCE, when Pharaoh Ramesses III of ancient Egypt deployed his navy against the Sea Peoples, mysterious raiders from the Mediterranean islands. At that time, ships were long and narrow, with several rows of oars, and carried soldiers armed with bow and spear. The main goal was to board the enemy's ship and fight hand to hand.

The Phoenician, Greek, and Cretan civilizations also had powerful fleets. But the turning point was the Battle of Salamis, 480 BCE, during the Greco-Persian Wars. The Greek fleet, using trireme vessels and the narrow strait of

Salamis, shattered the massive fleet of Xerxes. This battle showed that tactical skill and knowledge of local geography could overcome superior numbers.

The Rise of Rome and the Maritime Republics (200 BCE to 500 CE)

The Romans, who were not initially skilled sailors, used the innovation of the *corvus*, a movable boarding bridge, to defeat Carthage in the naval battles of the First Punic War. Rome's dominance over the Mediterranean, their sea, continued until the fall of the Western Empire.

In the medieval period, maritime republics in present-day Italy, such as Venice, Genoa, and Pisa, became the dominant powers of the Mediterranean. Venice, with its fleet of war galleys, challenged the Byzantine and Ottoman empires. In 1571, the Battle of Lepanto took place between the Holy League, Spain, Venice, the Papacy, and the Ottoman Empire, the last great battle fought with oared ships. The Ottomans were defeated, but this battle showed that the age of the galley was drawing to a close.

The Age of Sailing, Gun-Armed Ships (1500 to 1815)

With the discovery of the Americas and the expansion of colonial empires, large sailing ships with wooden hulls and several gun decks became the rulers of the seas. Spain, with its galleons, controlled the silver route, but Britain and the Netherlands quickly built more modern fleets.

The Spanish Armada, 1588, symbolizes the rise and fall of naval fortune. Spain's powerful fleet set out to conquer England, but smaller, more agile English ships, with longer-range guns and the use of fire ships, scattered and destroyed the Armada. This victory marked the beginning of British naval supremacy.

In the seventeenth century, the Anglo-Dutch Wars developed line-of-battle tactics: ships formed a line one behind another and fired from their broadside guns. The Battle of Texel, 1653, and the Four Days' Battle, 1666, became the model that continued until the Battle of Trafalgar.

Horatio Nelson, Britain's legendary admiral, at the Battle of Trafalgar, 1805, by defeating the combined French and Spanish fleet, permanently secured British naval supremacy. After that, the Pax Britannica, the British peace, ruled the oceans, and the British Empire commanded the seas without rival for a century afterward.

The Revolution of Steam and Armor: The Birth of Modern Naval Warfare

The Transition from Sail to Steam, and from Wood to Iron (1820 to 1880)

The invention of the steam engine freed ships from dependence on wind. The first steam warships appeared in the 1820s, but suffered from the vulnerability of their paddle wheels. The solution was the screw propeller, positioned beneath the water.

The next turning point was iron armor. During the Crimean War, 1853 to 1856, the French fleet, with armored vessels known as floating batteries, showed that wooden hulls were no longer effective against modern guns. But the real revolution occurred in the American Civil War: at the Battle of Hampton Roads, 1862, the Union ironclad Monitor, with a rotating turret, and the Confederate ironclad Merrimack, with sloped armor, clashed. This battle announced the end of the age of wooden ships and the birth of ironclad warfare.

In the 1860s, the Battle of Lissa, 1866, between Austria and Italy, showed that ramming, striking with an armored prow, was also an effective tactic. But over time, heavy artillery and thick armor determined the path of evolution.

The Age of the Battleship and Imperialism (1890 to 1914)

In the late nineteenth century, Britain, by building HMS Dreadnought in 1906, revolutionized warship design. This ship, whose main guns were all of a uniform caliber, twelve inches, mounted in rotating turrets along the centerline,

rendered every previous battleship obsolete. The age of the dreadnoughts began, and countries entered an exhausting arms race that was one of the important factors behind the First World War.

At the same time, emerging powers such as Germany, Japan, and the United States sought blue-water fleets. The Battle of Tsushima, 1905, in the Russo-Japanese War, utterly destroyed the Russian fleet and showed that Japan had become a great naval power.

The World Wars: The Peak of the Battleship and the Birth of the Submarine

The First World War (1914 to 1918): The U-boat Challenge

At the outset of the First World War, everyone expected a great clash of battleships. But apart from the Battle of Jutland, 1916, in which the German and British fleets faced each other with heavy losses, surface battles were limited. Jutland, though a tactical German victory, left Britain still dominant over the North Sea.

The real innovation was the submarine. Germany, by building the U-boat, Unterseeboot, employed a new strategy: unrestricted submarine warfare. These diesel-electric submarines, which could remain underwater for several hours, attacked Allied merchant and military ships without warning. In 1915, the sinking of the British passenger ship Lusitania by a U-boat caused the deaths of 1,198 civilians, including 128 Americans, and stirred world public opinion.

This event was one of the reasons for America's entry into the war.

In total, Germany's U-boats sank roughly five thousand merchant ships in the First World War. In response, the Allies organized shipping convoys escorted by destroyers and used early sonar devices, ASDIC, which reduced the submarines' effectiveness to some degree. Even so, the submarine was established as a strategic weapon.

The Second World War (1939 to 1945): The Battle of the Atlantic and the Peak of the U-boats

In the Second World War, submarines reached technical maturity. Germany, with a fleet of Type VII and Type IX U-boats and a new tactic called wolf packs, Rudeltaktik, led by Karl Dönitz, preyed upon Allied convoys in the Atlantic. The idea of the tactic was that one submarine would find a convoy and summon the others by radio, and then they would attack the ships together at night from the surface, since submarines of that era spent most of their time on the surface.

The Battle of the Atlantic, which continued from 1939 to 1943, was the longest continuous battle of the war. At its peak, U-boats sank hundreds of thousands of tons of Allied shipping each month. But three Allied technologies turned the tide: centimetric radar, mountable on aircraft and ships, which could see a submarine on the surface even at night; advances in sonar, ASDIC, for tracking submarines underwater; and the breaking of the Enigma code, the Allies had broken the code of U-boat communications and knew where the wolf packs were.

From 1943 onward, U-boat losses rose sharply. Germany lost nearly 780 U-boats over the course of the war, out of 1,162 built, and more than thirty thousand sailors drowned, the highest casualty rate among Germany's armed forces.

In the Pacific, American submarines, the Gato and Balao classes, carried out similar work against Japanese shipping. With their torpedoes, after the fuze problem was resolved, they succeeded in sinking nearly the entire Japanese merchant fleet and crippling the country's economy.

Great surface battles were also fought in the Second World War: the Battle of the Coral Sea, the first battle fought between fleets without direct visual contact, using carrier-based aircraft, the Battle of Midway, the turning point of the Pacific, the Battle of Guadalcanal, brutal night battles, the Battle of the Philippine Sea, the Marianas Turkey Shoot, and the Battle of Leyte Gulf, the largest naval battle in history, in which Japan used massive battleships such as the Yamato for the last time, but aircraft proved decisive.

At the end of the Second World War, Germany's legendary battleship Bismarck was sunk by a combination of ships and aircraft, and Japan's Yamato was also sent to the bottom in a massive air assault. The age of the battleship had ended, and the new rulers of the seas were the aircraft carrier and the submarine.

The Cold War: The Dominance of Aircraft and Nuclear Silence

The Nuclear Revolution: Endless Submarines

On January 17, 1955, the American submarine USS Nautilus, the world's first nuclear submarine, got underway. The unlimited power of its nuclear reactor allowed it to remain underwater for months and move at a speed greater than any diesel submarine. The Nautilus passed beneath the polar ice in 1958 and reached the North Pole.

The Soviet Union too quickly launched its own nuclear submarine program and entered a frenzied race to build the fastest, deepest-diving, and quietest submarines. The Typhoon-class submarines, up to forty-eight thousand tons, the largest in history, and the Alfa class, with a titanium hull and a speed beyond forty knots, were Soviet innovations.

But the strategic turning point was the ballistic-missile submarine, SSBN. The United States, with the George Washington class, 1959, and the Soviet Union, with the Hotel class, deployed intercontinental-range nuclear missiles aboard submarines. This meant that even if all the enemy's land bases were destroyed, a second nuclear strike could still be launched from the ocean depths. This concept of sea-based nuclear deterrence became the backbone of the Cold War.

Attack submarines, SSNs, such as America's Los Angeles class and the Soviet Victor class, had the mission of tracking and destroying the enemy's SSBNs. This cat-and-mouse game in the ocean depths, with extraordinarily sensitive sonars and near-impossible stealth, carried the constant risk of collision and confrontation, and several times brought the two sides to the brink of war, such as the crisis involving Yankee-class submarines in 1980.

Surface Battles and Missiles

On the surface of the sea, the Cold War witnessed limited but notable battles: the Suez War, 1956, the last major engagement fought with classic battleships, and the Six-Day War, 1967, and the Yom Kippur War, 1973, naval engagements between Israel and Arab states in which anti-ship missiles, such as the Soviet Styx and the American Harpoon, played the central role. The Battle of Latakia, 1973, was the first engagement in history fought entirely with missiles, with naval guns playing no role at all.

American Nimitz-class, and later George H.W. Bush-class, aircraft carriers became the symbol of naval power projection. Each carrier is a floating city with more than five thousand crew and seventy-five aircraft.

Submarines and Torpedoes: Deadly Silence in Detail

The Technical History of the Submarine: From Leather and Oar to Carbon Fiber

Stages in the evolution of the submarine: the idea's antiquity, Aristotle mentioned a device that allowed divers to breathe underwater. In the sixteenth century, Leonardo da Vinci sketched a design for an underwater ship but, fearing its misuse, never published it. In 1620, Cornelius Drebbel, a Dutchman in English service, built the first practical submarine, connecting it to the surface with oars and leather tubes. In 1776, David Bushnell used the Turtle in the American War of Independence against British ships. A soldier named Ezra Lee tried to attach it to HMS Eagle but failed, the first submarine attack in history. In 1800, Robert Fulton, an American, built the submarine Nautilus and offered it to Napoleon, but the French showed no interest. In 1863, Confederate submersibles: in the American Civil War, the southern states built the submarine Hunley, H.L. Hunley. In 1864, the Hunley, with a spar torpedo, sank the Union sloop Housatonic, the first successful sinking of a ship by a submarine in history, but the Hunley itself also sank and all its crew perished. From 1880 to 1900, the battery-and-diesel-electric-motor revolution: inventors such as John Holland, America, and Simon Lake built acceptable submarines. The United States Navy purchased its first submarine, USS Holland, in 1900. This submarine used a gasoline engine on the surface and battery power underwater,

the same system that continued until the Second World War. In the world wars, diesel submarines became the deadly hunters of the oceans. In 1954, the Nautilus, a nuclear submarine, a revolution in endurance and speed. In 1960, USS George Washington, the first SSBN, nuclear ballistic-missile submarine. Today, fourth- and fifth-generation submarines: the Ohio class, United States, the Columbia class, next generation, the Borei class, Russia, the Type 212, Germany, diesel with an air-independent propulsion, AIP, fuel-cell system, and the Kilo class, Russia, known as the black hole.

Stealth technology: a modern submarine must be quieter than the ocean itself. Sound-absorbent coatings, reduced propeller noise, seven-bladed propellers with skew-back design, vibration-dampened engines, and even the use of pump-jets instead of propellers in some classes, such as the Virginia, are all designed to achieve deadly silence.

The Torpedo: From Powder and Compressed Air to Laser Guidance and Supercavitation

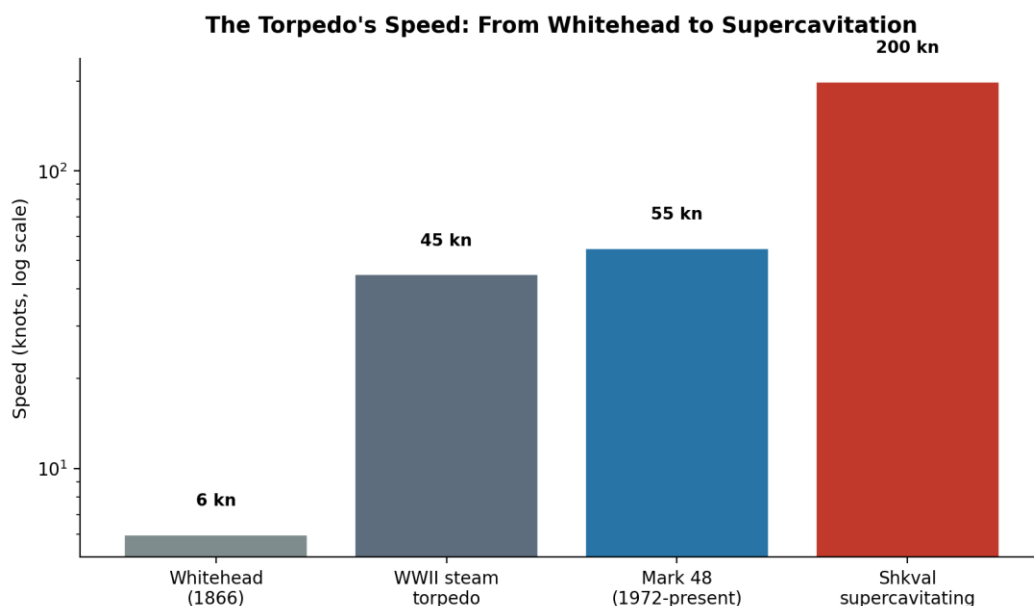


Chart: The torpedo's maximum speed from the first Whitehead design to modern supercavitating types, log scale (author's diagram, illustrative).

The torpedo is, in effect, an underwater self-propelled mine. Its evolution: early pioneers, in 1280 CE, Hasan al-Rammah, a Syrian engineer, in his book *Al-Furusiyya wa al-Manasib al-Harbiyya*, described a self-propelled device resembling a fiery egg. Some regard this as the earliest concept of the torpedo, though it was never practically built. In 1866, Robert Whitehead, an Englishman resident in Austria, built the first modern operational torpedo. Compressed-air engine, speed six knots, range 650 meters, an eight-kilogram powder warhead. Later, speed reached eighteen knots and range nine hundred meters. From 1870 to 1900, the world's navies adopted the torpedo. Destroyers were built to counter torpedo boats. In the First World War, more advanced torpedoes with gyroscopes for maintaining a straight course and adjusting depth appeared. Submarines used steam-alcohol or hot-air torpedoes. In the Second World War, three great innovations: magnetic, detonating beneath the hull via a magnetic field, contact, an impact fuze, and passive acoustic homing, following the enemy's sound, the famous German G7e/T4 Falke torpedo. In the Pacific, the American Mark 14 torpedo had many problems but was later fixed. In the Cold War and today: the wire-guided torpedo, the weapon can send sensor data to the submarine through a wire while in motion so its course can be corrected. The American Mark 48, in service since 1972, and the more advanced Mark 48 ADCAP version. The supercavitating torpedo, by creating a vapor bubble around the body, water friction is nearly eliminated and speed reaches beyond two hundred knots, 370 kilometers per hour. Russia has built the VA-111 Shkval torpedo, with an estimated speed of two hundred to 250 knots. Iran has also unveiled the Hoot torpedo with similar technology. Heavy and light torpedoes: heavy torpedoes, such as the Mark 48, for large submarines against ships, light torpedoes, such as the Mark 46 and Mark 54, for anti-submarine aircraft and helicopters. The rocket-torpedo, ASROC, a rocket that carries a light torpedo close to an enemy submarine, after which the torpedo drops into the water.

Guidance technology: the combination of active and passive sonar, thermal guidance, distinguishing hot from cold currents, propeller-pattern recognition, and computer processing has turned modern torpedoes into precision underwater munitions.

The Contemporary Era: Drones, Electronic Warfare, and the Future

Recent Conflicts and New Developments

Since the Cold War, no great naval battles have occurred, but local conflicts have shown that supersonic anti-ship missiles, surface and subsurface drones, and cyber warfare are serious threats.

The Falklands War, 1982: the Argentine cruiser General Belgrano was sunk by the British nuclear submarine Conqueror with Mark 8 torpedoes. In return, the British destroyer Sheffield was sunk by a French-Argentine Exocet missile.

Attacks on tankers in the Persian Gulf, the 1980s and 2019: the use of mines and the threat of small submarines.

The evolution of invisible submarines: the Chinese navy has built Yuan- and Shang-class submarines with pump-jet technology and reduced noise. Russia has fielded the Borei-A class, Yasen-M, with eight 650-millimeter torpedo tubes and the capability to launch Kalibr cruise missiles.

Unmanned underwater vehicles, UUVs: such as America's Sea Hunter, designed for mine-hunting and anti-submarine warfare. Some can operate autonomously.

The Future of War at Sea: Artificial Intelligence and Smart Torpedoes

Military experts believe the next generation of naval warfare will feature: unmanned surface and subsurface vessels; competition in sonar frequencies and electronic warfare to deceive enemy torpedoes; torpedo launches from satellites or long-range aircraft, capable of penetrating layered defenses; and fully silent submarines using magnetohydrodynamic, MHD, propulsion, though this remains in early stages.

Final Summary: Deadly Silence, Ruler of the Depths

The history of naval warfare shows that each time, a new technology has upended the equations of power: from the oared galley to the ship of the line, from the ironclad battleship to the aircraft carrier. But none has given meaning to the concept of deadly silence as much as the nuclear submarine equipped with smart torpedoes.

In the submarine, silence is not weakness but strength. Silence means being invisible, remaining undetected, and, at the right moment, delivering a strike that rises from the depths and shatters the pride of surface fleets. Today's torpedoes are also no longer Hasan al-Rammah's fiery egg, but hunters with an electronic brain and a precision measured in fractions of a degree.

Without doubt, as long as the seas remain an arena of competition among nations, the battle between hunter and hunted in the silent depths of the oceans will continue. And every vessel that moves upon the water must always remember that beneath it, deadly silence may lie in wait.

Special Feature

American and Russian Aircraft Carriers: From the Beginning to Today

Aircraft carriers are not only the steel giants of the seas; they are counted as symbols of power projection, deterrence, and national dominance over the world's oceans. In this survey, we trace two entirely different schools of thought and

engineering, the American school, focused on pure air combat, and the Russian school, with its aircraft-carrying cruiser approach, from the first steps to the most modern designs, and even designs that never touched the water.

American Aircraft Carriers: From the Second World War to the Ford and Beyond

After the Second World War, the United States Navy, correctly grasping the central role of carriers in the Pacific war, began a coherent program to maintain air superiority at sea. This program encompasses three distinct generations: the early postwar generation, which grew out of Second World War carriers, the generation of conventional supercarriers, and the final generation of nuclear carriers, which brought unlimited endurance.

The First Postwar Steps: The Essex and Midway Classes

After the Second World War ended, the United States Navy had two main types of carrier: Essex-class ships, roughly twenty-seven thousand tons, and the larger Midway-class ships. The many Essex-class carriers underwent a fundamental transformation through programs known as SCB-27 and SCB-125. In these upgrades, they were equipped with an angled flight deck instead of a straight one, the first angled control islands and deck-edge elevators were installed, and they received more powerful engines. In practice, these ships, built in the 1940s, remained in service into the 1970s. But the real turning point was the Midway-class carriers. Three of these ships, Midway, Franklin D. Roosevelt, and Coral Sea, weighing roughly sixty-four thousand tons at full load, went beyond the Second World War generation. Indeed, Midway was the first postwar carrier to receive an angled deck, heavier elevators, and, most importantly, operational capability for early jets such as the F-2 Banshee and F-3 Demon, giving it new life for the following two decades.

The Birth of the Supercarrier: The Forrestal, Kitty Hawk, and Enterprise Classes

The true age of supercarriers began with the Forrestal class. Four ships of this class, Forrestal, Saratoga, Ranger, and Independence, entered service in the mid-1950s. Their key feature was an angled flight deck alongside the longitudinal deck, and four powerful steam catapults that, for the first time, made simultaneous launch and recovery operations possible for heavy jets such as the F-4 Phantom and the A-5 Vigilante bomber. Even so, they still used ordinary steam-turbine engines, not nuclear, and so faced fuel limitations on operational range.

After Forrestal came the Kitty Hawk class, which also numbered three ships, Kitty Hawk, Constellation, and America. This generation was an improvement over Forrestal, with a more optimized elevator layout and a more powerful electrical system. Kitty Hawk and Constellation played a central role in the Vietnam War. But at the same time, the United States Navy took another revolutionary step: building the USS Enterprise, the world's first nuclear-powered aircraft carrier. Enterprise, with eight A2W reactors and an output of roughly 280,000 horsepower, had the capacity to carry more than ninety aircraft. Enterprise, carrying out Operation Sea Orbit in 1964 alongside two nuclear-powered escort ships, the cruiser Long Beach and the destroyer Bainbridge, circled the globe over sixty-five days without any refueling, showcasing the glory of nuclear propulsion.

The Unquestioned Dominance of the Nimitz Generation

Despite Enterprise's success, this ship, owing to its use of eight reactors and high maintenance cost, remained a unique example. But the experience gained from it led to the design of the Nimitz class, a class that, with only two much more compact and efficient A4W reactors, delivered the same output, 260,000 horsepower, with greater reliability and a smaller footprint. Nimitz and its ten sister ships, Dwight D. Eisenhower, Carl Vinson, Theodore Roosevelt, Abraham Lincoln, George Washington, John C. Stennis, Harry S. Truman, Ronald Reagan, and George H.W. Bush, have been the main pillar of American naval power for more than four decades. These ships, displacing roughly 102,000 tons at full load, 333 meters long, with the operational capacity of a ninety-aircraft air wing, are, in effect, floating airfields capable of launching air strikes anywhere in the world. Each ship of this class has four steam catapults capable of launching one aircraft every twenty to thirty seconds, though in practice, owing to elevator limitations and deck layout, the sustained operational rate is roughly one launch and one recovery per minute.

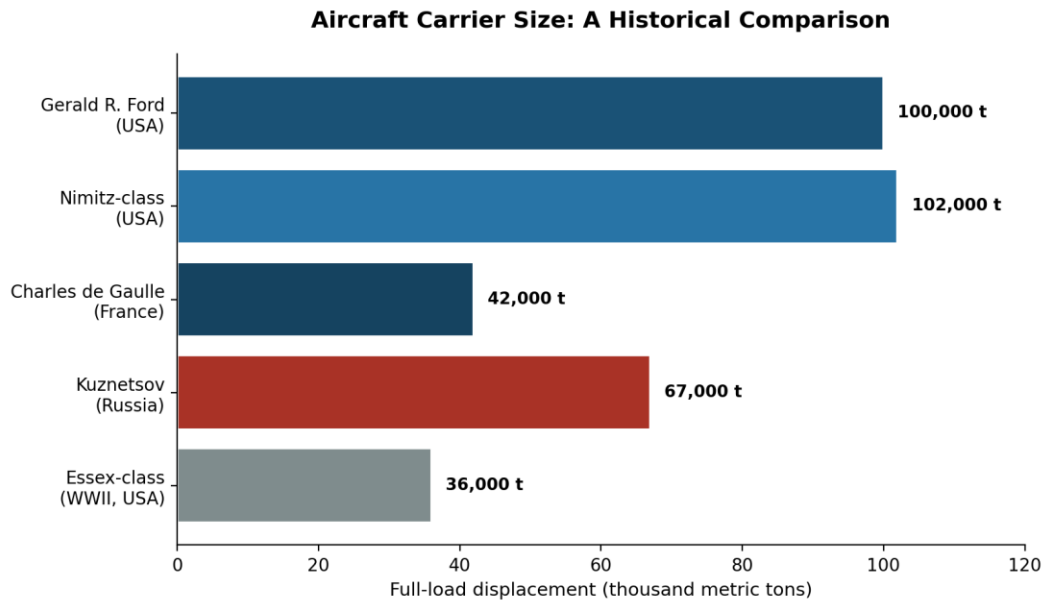


Chart: Full-load displacement of selected aircraft carriers across different eras (author's diagram, illustrative).

A Revolution Underway: The Gerald R. Ford Class and the Future

If the Nimitz class represented the maturity of steam and mechanical technology, the Ford class is a digital and electromagnetic revolution. The Ford, CVN-78, and her sisters, John F. Kennedy, CVN-79, Enterprise, CVN-80, in memory of the earlier nuclear carrier, and Doris Miller, CVN-81, are equipped with two new A1B reactors that generate far greater electrical output, roughly three times that of the Nimitz. This additional power is vital for operating new systems, the most important of which are the Electromagnetic Aircraft Launch System, EMALS, and the Advanced Arresting Gear, AAG. Unlike the steam catapult, which produces a sudden, unadjustable force, EMALS provides smooth, programmable acceleration matched to aircraft weight, from heavy manned aircraft to light drones. It also has a higher launch rate and wastes less energy. In addition, the Ford's flight-deck design is more optimized, and by shifting the island aft and to starboard, more space has been created for arranging aircraft and munitions. The number of elevators has been reduced from four to three, but they are of a new electromagnetic type with higher capacity. The new generation of Ford-class carriers, with greater reliability and a smaller crew, roughly six hundred fewer than the Nimitz, is expected to form the main body of the United States Navy until 2060.

Soviet and Russian Aircraft Carriers: A Different Approach, an Independent School

While the United States continued building ships aimed at pure air combat, the Soviet Union, under Khrushchev and then Brezhnev, held an entirely different view of aircraft carriers. Soviet ideology, for several decades, regarded large surface ships as vulnerable and wasteful, relying instead on long-range missiles and submarines. As a result, the ships the Soviet Union built were never aircraft carriers in the Western style, but were called aircraft-carrying cruisers, which, alongside carrying a number of aircraft, were themselves armed with massive anti-ship missiles.

The Moskva Class: A Platform for Hunting Submarines

The Moskva class, comprising two ships, Moskva and Leningrad, was built in the 1960s. They resembled not ordinary ships, but a combination of a surface ship at the front and a helicopter flight deck at the rear. Their displacement was roughly seventeen thousand tons, and instead of jet aircraft, they carried roughly fourteen to eighteen Ka-25 Hornet anti-submarine helicopters. Their main mission was hunting NATO ballistic-missile submarines and protecting their own missile fleet. They were armed at the front of the ship with one twin fifty-seven-millimeter gun and several surface-to-air missile systems. Though they could not fulfill the role of a classic aircraft carrier, they provided the Soviet Union with valuable experience in designing and operating with a flight deck.

The Kiev Class: The Peak of Aircraft-Carrying-Cruiser Thinking

In the 1970s, the Soviet Union took a larger step: the Kiev class, with four ships, Kiev, Minsk, Novorossiysk, and Baku, later renamed Admiral Gorshkov. These vessels, displacing roughly forty-three thousand tons, were a strange and unbelievable combination. The forward half of the ship resembled a heavy missile cruiser with every kind of weapon: twelve massive SS-N-12 Sandbox anti-ship missiles in four twin launcher pairs, SA-N-4 Gecko and SA-N-3 Goblet surface-to-air missile systems, and various anti-aircraft guns. At the rear of the ship, a three-quarter-length flight deck was fitted for operating vertical or short-takeoff aircraft. The main aircraft of these ships was the Yak-38 Forger, a vertical-takeoff fighter with very poor performance, limited range and weapons, and problems operating in hot climates, such as the Indian Ocean. After the Soviet collapse, Kiev and Minsk were sold to China and turned into museums and amusement parks. Novorossiysk was scrapped in South Korea in the late 1990s. But Baku, later renamed Admiral Gorshkov, found a second life, and after extensive reconstruction in India and renaming to Vikramaditya, entered Indian navy service as a pure aircraft carrier with a ski-jump flight deck and without the large offensive missiles.

The Kuznetsov Class: Approaching Global Standards

With the Kuznetsov class, the Soviet Union came closest to its most serious effort to build a true carrier. Admiral Kuznetsov, now Russia's only aircraft carrier, was launched in the late 1980s and had a half-sister named Varyag, which was later sold to China and, after completion, renamed Liaoning. Kuznetsov, displacing roughly sixty-seven thousand tons, 305 meters long, combines an angled flight deck with a ski-jump ramp at the bow that allows heavy fighters such as the Su-33 to take off with a light load, though not a full one. The fundamental difference between Kuznetsov and American ships was that it still remained loyal to the aircraft-carrying-cruiser concept: at the front of the deck, twelve vertical launchers for massive P-700 Granit anti-ship missiles, with a range of roughly six hundred kilometers, are fitted. Powerful air-defense systems, including the Kinzhal system, are also installed on it. Kuznetsov has faced chronic engine-room problems and low reliability in practice, and in recent years, after fires and numerous incidents, has become nearly non-operational. Indeed, this ship has not left port since 2018, and its status appears uncertain. Even so, from a historical standpoint, Kuznetsov symbolizes the last surviving remnant of the Soviet dream of a great surface fleet.

An Unfinished Dream: The Ulyanovsk Class, Had the Collapse Not Occurred

The largest and most advanced Soviet aircraft-carrier design was the Ulyanovsk class. This was a nuclear-powered ship displacing roughly eighty-five thousand tons, approaching the American Nimitz in size and power. The plan was for Ulyanovsk to use both a ski-jump ramp and two steam catapults for launching heavy aircraft, a massive step toward Western thinking. This ship was to carry roughly seventy aircraft, including the Su-33 and the Yak-44 AWACS aircraft. But in 1991, with the collapse of the Soviet Union, construction funding stopped, and the half-built hull was abandoned at the Nikolayev shipyard in Ukraine. The hull was ultimately scrapped for sale as scrap metal. With the death of Ulyanovsk, the idea of a powerful, American-style Russian aircraft carrier passed into history forever.

The Situation Today and Russia's Future, on Paper

After the Soviet collapse, Russia struggles even to maintain Kuznetsov. In plans that exist only on paper, several new designs, such as the Shtorm class, displacing one hundred thousand tons with nuclear propulsion, aimed at competing with the Ford, have been proposed, and another design called Lamantin has been a somewhat more modest initiative for a ship of roughly eighty thousand tons, but none of these designs has ever reached the construction phase and will likely remain unrealized this decade and even beyond. It was announced that the construction of two new aircraft carriers is included in Russia's arms program through 2045, but given budget problems, sanctions, and the priority given to ground warfare, these promises appear nearly impractical. What is certain is that the age of great Soviet aircraft carriers ended with the death of Ulyanovsk, and Russia today will have no notable aircraft carrier in service for several decades unless an economic and industrial miracle occurs.

Final Analysis and Comparison of Philosophies

Comparing the American and Russian paths in designing and building aircraft carriers is, more than a technical competition, the story of two geopolitical philosophies and two different understandings of naval power. America defines aircraft carriers as a global platform for power projection without needing land bases, and so emphasizes maximum air power, a fast flight cycle, and mission diversity; for this reason, powerful catapults, an angled deck, and efficient reactors are inseparable components of this school. On the other side, the Soviet Union, during the Cold War, owing to a belief that large surface ships were vulnerable to anti-ship missiles, never trusted in pure air power and insisted that its own ship also play the role of a missile cruiser. For this reason, Soviet aircraft-carrying cruisers carried a mass of massive missiles, and their aircraft played a complementary role. With the Soviet collapse, Russia lost both the means and the will to build and maintain such vessels to a large degree, while America, with long-term planning, not only kept the Nimitz fleet at its peak but, with the Ford generation, took a step toward technical transformation. Meanwhile, the dream of Ulyanovsk was buried forever at the Nikolayev shipyard, and its only legacy is the Chinese comrades of Soviet ships, Liaoning and a few others, which, having undergone complete reconstruction, have also taken on a more Western approach.

In a word, power over the oceans today and in the future remains in the hands of American supercarriers, which the Ford generation is set to continue into the middle decades of the twenty-first century, while Russia, at best, can hope to return Kuznetsov to the open sea, a dream that, with rising costs and the vessel's gradual aging, grows more distant and unattainable each year.

Chapter 21

Mines, Grenades, and Non-Lethal Weapons: Defensive Clothing

This chapter examines three seemingly separate but, in practice, interwoven domains of personal-defense technology and offensive weaponry. The first section is devoted to the history of defensive clothing against bullets and edged weapons, a journey from the earliest leather armor to Kevlar vests and liquid-armor technologies. The second and third sections address two categories of portable explosive weapons, landmines and grenades, each of which has left a lasting effect on the nature of conventional and asymmetric warfare. The fourth section introduces non-lethal weapons, tools that, in theory, have shifted the line between crowd control and killing. Throughout the chapter, eyewitness accounts, from frontline soldiers to civilian victims, appear as living documentation alongside technical and historical analysis.

Part One: A History of Armor and Defensive Clothing Against Arrow and Bullet

Definition and the Basic Function of Armor

Armor, in its broadest definition, is any covering or equipment designed to reduce a combatant's vulnerability to enemy weapons. The physical function of armor rests on three principles: absorbing impact energy, such as the deformation of a metal plate or the breaking of Kevlar fibers, dispersing force, spreading the pressure of a bullet over a larger area of the body, and deflecting the projectile's path, achieved through sloped surfaces on helmets and plate armor. Throughout history, armor materials have evolved from leather and bone to bronze, iron, steel, and finally to synthetic polymer fibers, ceramics, and nanomaterials.

Antiquity: The First Steps in Protective Covering

Armor in Mesopotamia and Egypt

Archaeologists have discovered the oldest known armor in the royal cemetery of the city of Ur in present-day Iraq, roughly 2500 BCE. This armor was made of small copper or bronze plates shaped like fish scales, sewn onto a double-layered leather backing. Each scale was roughly one millimeter thick, and the scales overlapped to create a covering that was flexible yet resistant to arrow and spear. In ancient Egypt, the pharaoh's charioteers used bronze scale armor, while ordinary infantry usually went into battle with only a leather shield and woven-reed helmets.

The Bronze Revolution in Greece and Anatolia

In the second millennium BCE, Mycenaean civilization, ancient Greece, built armor known as the Dendra armor, a single-piece bronze cuirass covering the entire upper body from shoulder to waist, weighing up to eighteen kilograms. This armor, discovered in 1960 in a tomb near the village of Dendra, was so sturdy that, after 3,500 years, it remains usable, in 2023, Greek researchers, by reconstructing it, showed that a soldier could fight in it for eleven hours. In the same period, the Hittites in Anatolia used scale armor with iron scales, when iron was still very costly and a symbol of power.

Armor in Ancient Iran: From the Achaemenids to the Sasanians

In Achaemenid Iran, 550 to 330 BCE, heavy infantry known as the Takabara, meaning shield-bearers, were covered in leather scale armor with bronzescales. But the peak of Iranian armor development belongs to the cataphract cavalry. Cataphracts means the fully armored; both horse and rider, from head to hoof, were covered in a layer of metal scales or bronze plates. Herodotus, the Greek historian, in his book *The Histories*, expresses astonishment at seeing these horsemen, who appeared to be men of iron. In the Parthian era, 247 BCE to 224 CE, azari leather armor became common; several layers of water-buffalo hide were bonded with natural adhesive and then covered with iron scales. In the Sasanian era, 224 to 651 CE, a great transformation occurred: chainmail, or joshan, reached its peak perfection. Sasanian chainmail was made of thousands of small iron or steel rings, five to ten millimeters in diameter, each formed from wire wound around a metal rod and then riveted or welded. The rock relief at Naqsh-e Rostam in Fars shows a Sasanian king, Ardashir or Shapur, mounted on horseback and wearing chainmail down to the knee.

Roman Armor: Lorica Segmentata

The legions of ancient Rome used various types of armor. Lorica hamata was chainmail, borrowed from the Celts. Lorica squamata was scale armor. But the most famous is lorica segmentata, armor made of wide steel strips arranged horizontally across the chest and vertically over the shoulders. This armor, used from roughly 9 BCE to the third century CE, was lighter than chainmail, roughly nine kilograms, and more resistant to spear thrusts, since the steel strips spread the force of impact over a wider area.

The Middle Ages: The Golden Age of Knightly Armor

The Dominance of Chainmail, the Hauberk

From the ninth to the thirteenth century CE, chainmail, called haubergeon in France and brünne in Germany, was the standard for European knights. A complete hauberk consisted of a shirt of steel rings, often with flattened rivets to increase contact area, covering from the neck to the knee. Its weight ranged from ten to fifteen kilograms. At the Battle of Hastings, 1066, Norman knights led by William the Conqueror, wearing chainmail and nasal helmets, crushed Anglo-Saxon infantry. Even so, chainmail was vulnerable to blows from heavy cavalry lances and longbow arrows, as at the Battle of Crécy, 1346, where thousands of French knights died beneath a rain of English archers' arrows.

The Rise of Plate Armor

From the late thirteenth century, solid metal plates were gradually added over more vulnerable areas such as the chest, knees, and elbows. These plates were small at first but gradually grew larger. In 1420 CE, full plate armor reached its perfection in Italy, the Milanese style, and Germany, the Gothic style. A complete Gothic suit of armor consisted of twenty to thirty separate pieces: a breastplate, cuirass, a backplate, shoulder guards, pauldrons, arm guards, rerebraces, steel gauntlets, thigh guards, cuisses, shin guards, greaves, and advanced helmets such as the sallet or armet. The weight of a complete suit of armor ranged from twenty to thirty kilograms, but owing to the intelligent distribution of weight across the shoulders, waist, and legs, a trained knight could run, leap onto a horse, lie on his back and rise again, and even perform coordinated swimming, modern tests at the Royal Museum of the Armed Forces in Brussels have proven this.

Armor in the Islamic World and Iran

In Islamic lands, armor-making flourished in cities such as Damascus, Aleppo, Isfahan, and Shiraz. A type of composite armor combining chainmail rings and small metal plates, called *char-aineh*, four mirrors, since it had four large plates on the front, back, and both sides of the chest, was common. This armor combined the flexibility of mail with the strength of plate. Examples of this armor are kept in the Louvre and the Topkapi Museum in Istanbul, showing the delicate gold work and engraving on Damascus steel. In Ferdowsi's *Shahnameh*, *khaftan*, a type of short leather armor reinforced with metal scales, and *joshan*, chainmail, are mentioned repeatedly.

The Decline of Armor Against the Firearm (Sixteenth to Eighteenth Centuries)

The introduction of the flintlock firearm, the arquebus and then the musket, onto sixteenth-century battlefields brought the age of plate armor to an end. At the Battle of Pavia, 1525, Spanish musketeers hidden among the bushes easily pierced the heavy armor of French knights, who had believed that no bullet could penetrate steel. From that time, armor was gradually reduced to pieces such as the cuirass, breastplate, and morion, a hemispherical helmet. Heavy cuirassier cavalry in the Napoleonic Wars still used steel breastplates, but this armor was no longer effective against the direct fire of new guns, with a muzzle velocity of four hundred to five hundred meters per second, and mostly protected against sword and bayonet.

Rebirth in the Nineteenth Century: Steel and Silk Vests

The American Civil War, 1861 to 1865, was the first serious attempt to revive bulletproof armor with new technology. Both the Union and the Confederacy built numerous examples of soldier's vests, two cold-rolled steel plates, three to five millimeters thick, covered with a layer of wool cloth or rubber. The weight of these vests sometimes reached eight kilograms, and they could stop only slow bullets, under two hundred meters per second, and buckshot. In 1881, Dr. George E. Goodfellow in Chicago offered a vest made of several layers of silk cloth. In testing, this vest stopped a .38-caliber bullet fired at 220 meters per second. Even so, its high price, equivalent to two thousand dollars today, and the need to replace it after a few impacts prevented widespread adoption. It is worth noting that Archduke Franz Ferdinand, heir to the Austrian throne, wore a similar silk vest on the day of his assassination in Sarajevo, 1914, but the bullet struck his neck, and the vest offered no protection there.

The World Wars: Steel and Nylon Armor

In the First World War, the Germans introduced the famous *Stahlhelm* steel helmet, with a lowered brim to protect the neck and back of the head. The British used the Brodie helmet, resembling a miner's bowl-shaped hat, and the French the Adrian helmet, with a raised crest. But more important than the helmet was the emergence of the infantry breastplate. Late in the war, the Germans built the *Grabenpanzer*, trench armor, weighing five kilograms, made of two steel plates for the chest and abdomen, capable of withstanding close machine-gun fire, up to fifty meters. Owing to its weight, it was given only to snipers and trench guards.

In the Second World War, the United States produced the M12 vest for the pilots of B-17 and B-24 bombers. This vest had several pockets into which rectangular steel plates four millimeters thick were placed, with a total weight of roughly ten kilograms. The Soviet Union also built the SN-42 armor for assault teams, a steel breastplate that could stop a bullet from a German MP-40 submachine gun at one hundred meters. On the Pacific front, American forces used the M1 vest, which had layers of nylon reinforced with aluminum plates and was effective against mortar fragments but was penetrable by rounds from the Arisaka rifle, Type 99, 7.7 caliber.

The Kevlar Revolution: An Invention That Changed the World

Stephanie Kwolek and the Birth of Kevlar

In 1964, Stephanie Kwolek, a chemist working for the DuPont company, while researching liquid-crystal polymers for making lightweight, durable fibers for automobile tires, arrived at an unexpected result. She dissolved poly-paraphenylene terephthalamide in a special solvent, and when she passed the solution through a fine filter, she obtained silk-like, white-colored fibers with astonishing mechanical properties: a tensile strength of 3.6 gigapascals, compared to 0.4 gigapascals for steel, and a Young's modulus of roughly 130 gigapascals. In other words, Kevlar fibers were

five times stronger than steel and twice as strong as fiberglass, but with a density of only 1.44 grams per cubic centimeter, less than half that of aluminum. DuPont brought this material to market under the trade name Kevlar in 1971.

The First Kevlar Vests

The first soft Kevlar bulletproof vest was built by Lester Shubert, a scientist at the American National Institute of Justice. He sewed sixteen layers of Kevlar 29 into a single piece. In a 1976 test, this vest stopped a .38-caliber bullet, police special type, fired at 280 meters per second, while weighing only 1.2 kilograms. In 1978, the New York Police Department ordered two thousand vests, and in 1985 the United States Department of Defense introduced the PASGT vest, Personnel Armor System for Ground Troops, combining thirty layers of Kevlar with alumina-quartz ceramic plates. This vest protected against nine-millimeter Parabellum rounds, 360 meters per second, and mortar fragments.

The Evolution of Protection Levels

Today, the NIJ standard, National Institute of Justice, defines six protection levels for bulletproof vests. Level IIA: stopping a nine-millimeter bullet at 321 meters per second and a .40-caliber bullet at 310 meters per second. Level II: similar to IIA but at higher speeds, 343 and 323 meters per second. Level IIIA: stopping a .44 Magnum bullet, 445 meters per second, and a nine-millimeter submachine-gun round, 426 meters per second. The most common level for police. Level III: stopping a 7.62×51-millimeter steel-jacketed bullet at 838 meters per second, this level requires hard plates, ceramic or steel. Level IV: stopping a .30-06 armor-piercing bullet at 884 meters per second.

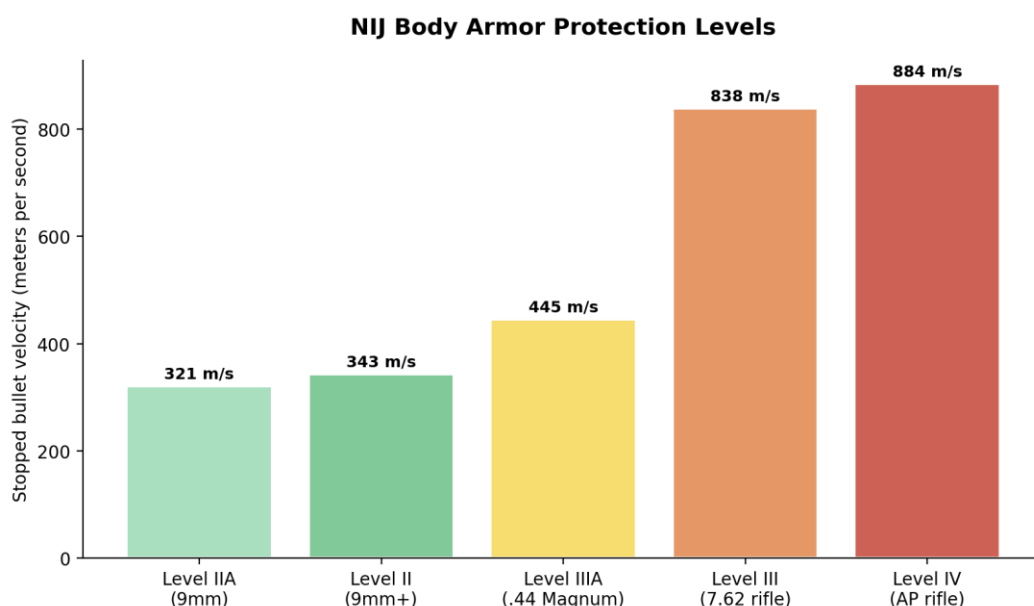


Chart: NIJ ballistic protection levels and the bullet velocities they are rated to stop (author's diagram, based on published NIJ standards).

Modern vests, such as the CRYE PRECISION model, use a combination of KM2 Kevlar, Dyneema, and silicon carbide or boron carbide plates. A Level IIIA vest weighs roughly 1.5 to two kilograms, while Level IV can reach eight to twelve kilograms.

Eyewitness Accounts: Voices from the Battlefield

Soldier Timothy Gilboe (Afghanistan, 2007)

Gilboe was a member of a special operations team in Kandahar province. In a night ambush, a Taliban fighter fired at his chest from twenty meters with a Kalashnikov rifle, 7.62×39 caliber. The bullet struck the ceramic plate of his Level IV vest. Gilboe fell to the ground and bruised his ribs, but his heart and lungs remained unharmed. He later said in an

interview with Army Times magazine that the sound was like a sledgehammer on an anvil, that his breath caught, that he thought he was dead, but that when he reached under his clothing and felt no hole, he realized the vest had saved him. The bullet lodged in the vest is still kept in his room.

Sergeant Myers (Fallujah, Iraq, 2004)

Myers, a United States Marine, during the Second Battle of Fallujah, Operation Phantom Fury, was struck by six 7.62-caliber bullets, from Baathist rifles and likely a sniper, in various parts of his vest and helmet. Four bullets struck his Level IIIA vest, which later turned out not to have been rated to resist this caliber, though the rounds were likely old and slow, and two struck his brimmed PASGT helmet. He suffered only bruising and ringing in his ears. After returning, Myers recorded a video of the six bullets lodged in the Kevlar layers and posted it online under the title Six Reasons I'm Alive.

Sergeant Javad Miller (Kirkuk, Iraq, 2006)

Miller, of the 101st Airborne Division, on a foot patrol through the streets of Kirkuk, was targeted by a sniper with a Dragunov rifle, 7.62×54R caliber. The bullet struck the left side of his vest. According to the medical report, eighty-five percent of the bullet's energy was absorbed by the ceramic plate and another ten percent by the Kevlar layers beneath it. Miller was discharged from the hospital with two broken ribs and a superficial hematoma. He later said that he no longer looked at the vest as a piece of equipment; the vest was his brother in arms.

Los Angeles Police Officer (2011)

Responding to a call about an armed robbery in North Hollywood, Officer Eric Sanchez encountered a criminal armed with a nine-millimeter pistol. The criminal fired at the officer's chest from three meters. The officer's Level IIIA Kevlar vest, Second Chance model, stopped the bullet. Sanchez, having fallen onto his back, fired two return shots and wounded the criminal. The incident report stated that the vest had a deep, one-centimeter dent in the outer layer, that the nine-millimeter FMJ bullet had penetrated to the last of the third layer but had not reached the fourth layer, and that Officer Sanchez was able to return to duty less than a minute after getting up.

Captain Khalid Martinez (Colombian Special Forces, 2019)

In an operation against FARC guerrillas in the jungles of southern Colombia, Martinez was targeted twice: once by a Galil rifle, similar to the AK, striking the back of his vest, and once by a Beretta pistol, striking his side. His vest was made of a new generation of Dyneema, Dyneema HB50, an ultra-high-molecular-weight polyethylene fiber fifteen times stronger than steel. In an interview with Soldier of Fortune magazine he said that the first bullet threw him forward; he never felt the second, likely because he was already in motion from the impact; after the operation, doctors found two purple marks on his back and side; they said the vest had neutralized roughly ninety-five percent of the energy; he had lived two lives.

New Technologies and the Future of Armor

Dyneema and Zylon

Dyneema, UHMWPE, made by the Dutch company DSM, is lighter than Kevlar, with a density of 0.97, which floats on water, and has fifteen times the tensile strength of steel. Dyneema vests are forty percent lighter than Kevlar and show greater resistance to moisture and chemicals. Zylon, made by Toyobo, is, in the short term, even stronger than Dyneema, but research has shown that Zylon degrades from ultraviolet light and water vapor and loses up to fifty percent of its strength within two years, which is why the Japanese police collected all their Zylon vests in 2005.

Liquid Armor, Shear-Thickening Fluid

Researchers at MIT and the University of Delaware have built a non-Newtonian fluid made of silica nanoparticles, five hundred nanometers in diameter, in polyethylene glycol. Under normal conditions, the fluid is soft and pliable

and passes between the fabric fibers, the vest is flexible. But when a bullet strikes it, at a strain rate above one thousand per second, the silica particles lock together and the fluid's viscosity increases thousands of times within milliseconds, becoming as hard as steel. This technology remains at the laboratory-sample stage.

Self-Healing, Bio-Inspired Armor

The United States Defense Advanced Research Projects Agency, DARPA, is working on armor containing microcapsules of liquid adhesive. When a crack forms in the armor, for example after a bullet impact, the capsules rupture and the adhesive flows out and fills the crack. Another example uses spores of the bacterium *Bacillus subtilis*, which rupture on impact and produce calcium metabolites that harden the armor's surface. This technology was tested on ceramic armor in 2022 and has shown it can increase resistance to a second impact by up to thirty percent.

Part Two: Landmines, Silent Death Underfoot

Definition and Legal Classification

A landmine, according to the definition of the Ottawa Convention, 1997, is munitions designed to be placed under, on, or near the ground surface and designed to explode from the presence, proximity, or direct contact of a person or vehicle. Mines are divided into two main categories: anti-personnel landmines, APL, aimed at killing or wounding infantry soldiers, and anti-tank mines, AT, designed to disable or destroy armored vehicles. A third category, anti-mine mines, also exists, used to detonate enemy mines. The most terrible feature of anti-personnel mines is that their designers intend wounding, not death: a wounded soldier occupies two or three other soldiers and disrupts the unit. For this reason, many anti-personnel mines, such as Russia's PMN, are designed to sever the victim's foot at the ankle or knee while keeping them alive.

The First Recorded Uses in History

The first documented military use of a landmine is attributed to the American Civil War. In 1862, Confederate General Gabriel Rains buried barrels of gunpowder, equivalent to fifty to one hundred kilograms, with a slow fuze and a simple pressure detonator, along the path of advancing Union forces at Yorktown. When soldiers stepped on the barrels, the fuzes ignited and the barrels exploded. General Rains wrote in his report that this method of defense had a remarkable effect in creating terror. Shortly after, Confederate Brigadier General Rains's colleague, Beauregard, built the first modern pressure mine: he hollowed out a twelve-pound cannonball, filled it with powder and fragments, shot pellets, and mounted a friction detonator, like a gun primer, on it. When a person stepped on it, the detonator ignited.

The Russo-Japanese War, 1904 to 1905, witnessed the first extensive use of anti-personnel mines. The Russians, desperate in defending Port Arthur, present-day Lüshunkou, China, buried thousands of small naval mines around their trenches. Each mine consisted of a cast-iron shell fifteen centimeters in diameter, containing four hundred grams of black powder and a pressure detonator. These mines were effective in causing severe casualties among Japanese soldiers, but many were never collected after the war and continued to claim Chinese civilian victims into the 1930s.

The First World War led to rapid mine evolution. The Germans developed the Stockmine: a wooden box measuring twenty by twenty by ten centimeters, filled with TNT, with a spring-loaded pressure detonator on top. The advantage of this mine lay in its wooden body: metal detectors, which were primitive at the time, could not identify it. The British built the S.T.A.R. mine, made from a tin can, and, to deceive the enemy, a small coin or metal object was placed on top to trigger a false metal-detector reading.

The Second World War: A Leap in Diversity and Numbers

In the Second World War, more than three hundred million mines, estimated, were laid across every front. The most famous anti-personnel mine in history was the German S-mine, Schrapnellmine, known as the bounding mine or Bouncing Betty. Its mechanism was remarkable: when the victim pressed on the mine's three sensitive prongs, a chemical detonator ignited a slow powder charge in the central tube. After 0.3 seconds, by which time the mine had risen to waist height, roughly 1.5 meters, a main charge at the base of the mine detonated, and its steel body turned

into as many as 360 fragments, spherical pellets or small cubes. Its lethal radius was twenty meters, and its wounding radius reached up to one hundred meters. The S-mine weakened Allied morale more than any other weapon in the Second World War.

The Soviet Union built the PMD-6 mine, a wooden mine, a rectangular wooden box with two hundred grams of TNT powder. The box's lid was held closed by a pressure spring; when someone stepped on the lid, the spring released and the detonator ignited. The PMD-6, owing to its fully non-metallic wooden body, cannot be detected even by today's advanced metal detectors, which is why it is still in use in Ukraine and Syria.

The United States built the M2A3 mine, an elongated, oval mine with a steel body containing 450 grams of TNT. In the Pacific, the M2A3 was planted along likely Japanese advance routes and, owing to its small size, eight centimeters in diameter, was easily concealed.

On the Eastern Front, Germany and the Soviet Union made extensive use of anti-tank mines. The Soviet TM-35 mine was a round metal box, twenty-five centimeters in diameter, with a threshold pressure of two hundred kilograms, only tanks and heavy trucks. The Germans built the Tellermine 42, with a steel body containing 5.5 kilograms of TNT, capable of severing a T-34 tank's track with a single explosion.

After the War: Global Contamination and Human Catastrophes

After the Second World War, it is estimated that more than 110 million mines were laid in seventy countries around the world. The Cold War and colonial conflicts increased this number. Vietnam, war of 1955 to 1975: the United States dropped more than two hundred million mines, mainly BLU-43 and BLU-44 Dragontooth, small plastic, diamond-shaped mines, along the Ho Chi Minh Trail, the Viet Cong's logistics network. It is estimated that, to this day, three to five million mines remain in Vietnam, Laos, and Cambodia. In Cambodia, killer mines, the local name for the Russian PMN mine, still claim roughly one hundred victims annually. Aki Ra, a Cambodian human-rights activist who was himself a Khmer Rouge child soldier, had, by 2023, disarmed more than fifty thousand mines by hand. His mine museum in Siem Reap displays thousands of amputation devices, artificial legs, canes, and wheelchairs.

Afghanistan is one of the most contaminated countries: from the Soviet invasion, 1979 to 1989, through civil wars and the American occupation, more than ten million mines have been laid in Afghan soil. The Soviet PMN mine, known as the killer mine, has a threshold pressure of five to fifteen kilograms, meaning even a child can trigger it. The Red Cross estimates that from 1989 to 2023, more than sixty thousand Afghans have fallen victim to mines, forty percent of them children under fifteen. The account of a child victim named Fazl Ahmad from Kandahar province, 2018: he recalls herding sheep; the sky was cloudy and the light dim; his foot stepped on something round and yellow; for a moment he saw fire, and then everything went black; when he opened his eyes in the hospital, his right leg was gone above the knee; he asked how he would ever run again; his mother wept.

In Bosnia and Herzegovina, the 1992 to 1995 war left more than one million mines behind. Many were laid in farmland and apple and plum orchards. As of 2023, two thousand restricted zones still exist in Bosnia, marked with skull-and-crossbones signs.

The Ottawa Treaty and the Effort at Eradication

On December 3, 1997, in Ottawa, Canada, the Treaty on the Prohibition of Anti-Personnel Mines, known as the Ottawa Treaty or the Mine Ban Convention, was signed with 122 countries present. Its main provisions: first, an absolute ban on the production, stockpiling, transfer, and use of anti-personnel mines; second, a commitment to destroy all existing mine stockpiles within four years; third, a commitment to clear contaminated land within ten years; and fourth, a commitment to assist mine victims. As of 2023, 164 countries have joined this treaty. But the United States, Russia, China, India, Pakistan, North Korea, Iran, Egypt, and Israel remain non-members. These countries argue that anti-personnel mines are necessary for defending long borders and against armored invasion, India and Pakistan along the Kashmir border, North Korea in the demilitarized zone with South Korea. In response, the International Campaign to Ban Landmines, ICBL, a coalition of 1,300 non-governmental organizations, won the Nobel Peace Prize in 1997.

Mine-Clearance Technology

Mine-clearance methods fall into three categories: mechanical, animal, and chemical-robotic. Mechanical: heavy roller machines, such as Germany's Keiler, which strike the ground with chains or steel cables to detonate mines. A bulldozer blade then collects the soil. Drawbacks: loud noise, heavy weight, forty tons, and ineffectiveness on rocky ground. Animal: giant African pouched rats, *Cricetomys gambianus*, called HeroRATs. These rats are sensitive to the smell of TNT, and their weight, one to 1.5 kilograms, is light enough not to detonate a mine, and they can search two hundred square meters in twenty minutes, a task that takes a human with a metal detector five days. The organization APOPO has, since 2000, disarmed more than 150,000 mines with the help of these rats. Robotic and drone: small robots, such as Afghanistan's Mine Kafon, that walk using GPS and strike the ground with a small rotating hammer; the sound of the explosion is recorded and a mine map is produced. Drones equipped with ground-penetrating radar, GPR, can detect plastic mines by their dielectric difference. Genetically modified plants: researchers at the University of Copenhagen have genetically engineered the *Arabidopsis*, thale cress, plant so that, in the presence of dinitrotoluene, a chemical released by TNT leakage, its leaves change color from green to red. Unmanned aircraft can see this coloring from an altitude of three hundred meters and produce a map of contaminated fields.

Part Three: The Grenade, the War Potato in Infantry Service

History: From the Hand Mortar to the Modern Grenade

The first forms of the grenade appeared in the Byzantine Empire, seventh century CE: Byzantine soldiers filled clay jars with Greek fire, a combination of naphtha, sulfur, and lime, attached a slow-burning fuze, and threw them at the enemy. The Chinese, in the tenth century CE, used bamboo tubes filled with gunpowder and metal fragments; they called these giant firecrackers *zhen tian lei*, heaven-shaking thunder. In the Song dynasty, 960 to 1279, cast-iron grenades appeared, at first spherical with thick walls and a small hole for the fuze. The Mongols carried this technology west after their invasion of China.

In Europe, the name grenade comes from the French word for pomegranate, since the fragments after the explosion resemble the seeds of a red pomegranate. In the sixteenth century, hollow iron grenades with slow-burning fuzes became standard in European armies. Soldiers who specialized in throwing grenades were called grenadiers. Grenadiers were the tallest and strongest soldiers in any battalion, since early iron grenades weighed two to three kilograms and had to be thrown with one hand. At the Battle of Waterloo, 1815, British Guards grenadiers with Koehler grenades scattered a number of French battalions.

The First World War: A Revolution in Design

The First World War brought a leap in the standardization and mass production of grenades. Three main models emerged.

The Mills bomb, Britain, 1915 model: a cast-iron body with a hexagonal, notched pattern, like a pineapple. When the grenade exploded, the body broke along its grooves into fifty to seventy uniform fragments. Its safety mechanism was a pin and a spring-loaded lever. After pulling the pin and throwing, the lever released and ignited a slow fuze for four seconds. Its lethal radius was ten meters, and its wounding radius reached up to fifty meters. The Mills bomb was so successful that, with minor changes, it remained in use through the Second World War and even into the 1960s.

The German stick grenade, Stielhandgranate 15: a cylindrical body of thin steel sheet, filled with TNT, attached to a wooden handle. At the end of the handle was a porcelain ball, Brennzünder, pulling which activated a friction spool and ignited a 5.5-second fuze. Advantage: more accurate and longer throwing distance, up to forty meters. Drawback: less fragmentation, since the thin body mainly produced blast rather than fragments. Its nickname was the potato masher, since Allied soldiers said its shape resembled a kitchen masher.

The French Viven-Bessières grenade: a rifle grenade, mounted on the gun barrel and launched with a blank cartridge. These grenades had fins to stabilize them in flight.

Types of Modern Grenades After the Second World War

After the Second World War, grenades were divided by application into the following types.

Fragmentation, offensive, grenades: optimized for killing personnel with fragments and blast. The famous example is America's M67, successor to the Mills bomb. A spherical steel body with 385 grams of Composition B, a mixture of RDX and TNT, a lethal radius of fifteen meters, and a wounding radius up to 250 meters. Weight 390 grams. In service since 1968.

Defensive grenades: more fragmentation and a shorter lethal radius, since the thrower is assumed to be under cover.
Example: the French F1, weighing six hundred grams with a ten-meter radius.

Chemical grenades: including tear gas, America's M7A3, containing 130 grams of CS gas, smoke grenades, the M18, in three colors, red, green, yellow, for signaling, and white phosphorus grenades, the M34, creating fire and thick smoke; its use against people in residential areas is considered a war crime.

Flash-bang, stun, grenades: developed in the 1970s by Britain's Special Air Service, SAS, for counter-terrorism operations. The M84 grenade has an aluminum body with small holes, for light and sound to escape. Contents: 4.5 grams of magnesium and ammonium nitrate. Light output: seven million candela, equivalent to two million candles, for 0.1 seconds; sound: 170 to 180 decibels, at one meter, capable of rupturing an eardrum. Blinding distance up to five meters.

Thermobaric grenades: for bunkers and enclosed spaces. The Russian example is the RGO-90. First, a small charge consumes the oxygen in the air and disperses an aerosol cloud, aluminum powder; a second later, a second detonator ignites the cloud and creates a powerful suction wave, more than four hundred kilopascals, that ruptures the lungs.
Not banned, but its use in urban areas is controversial.

Operating Mechanism: Minutes and Milliseconds

A modern grenade uses a chemical-mechanical detonator. The stages after pulling the pin: first, the spoon, held down by the palm's pressure, is released. Second, a spring throws the spoon off, and it strikes a small hammer. Third, the hammer activates a primer, made of lead styphnate, sensitive to impact. Fourth, the initial spark ignites the slow fuze, a reliable fuze burning at a rate of thirty millimeters per second, typically four to five seconds. Fifth, the end of the fuze reaches a secondary detonator, lead azide, which produces a stronger spark. Sixth, the secondary detonator explodes the main charge, TNT, RDX, or Composition B. The main charge's reaction speed is roughly eight thousand meters per second, the detonation wave, which throws the body outward. Body fragments travel at an initial speed of roughly two thousand meters per second, six times the speed of sound, and can pierce skin up to a radius of 150 meters.

Legal Limitations and Catastrophes

The 1980 Geneva Convention, Protocol II, restricts the use of air-dropped grenades and small mines, under ten centimeters, in civilian areas, but hand grenades are permitted in most armies. Even so, using a grenade against civilians is a war crime. In the civil wars in Syria and Yemen, tens of thousands of civilians have been killed by hand grenades containing extra fragments, such as nails and screws, built by irregular forces. These improvised grenades are known in the Middle East as Syrian pineapple bombs.

Part Four: Non-Lethal Weapons, the Line Between Control and Torture

Definition and Philosophy

A non-lethal weapon, NLW, refers to a tool designed to incapacitate people or equipment with a minimal probability of death or permanent injury. In theory, these weapons replace bullets, batons, and lethal gases. The European Police Forces regulation, 2015, defines four criteria for a non-lethal weapon: first, its effect must be reversible, the person returns to normal within minutes to hours; second, the probability of death must not exceed 0.1 percent; third, it must not cause permanent disability, blindness, deafness, amputation; and fourth, it must allow a defined dose, the officer must be able to control the level of effect. Even so, in practice, many of these weapons are either lethal or, under certain conditions, heart disease, pregnancy, young age, lead to death.

History: From the Baton to the Laser

The baton, a wooden or metal club, is the oldest non-lethal weapon. The ancient Romans used the fustis, a knotted club, to disperse crowds. In the nineteenth century, London police used a lead-loaded truncheon, which, if it struck the head, was often lethal. In 1990, the telescopic baton, ASP, was introduced, which collapses and is lightweight.

Police dogs: first used by the Spanish in the sixteenth century to control indigenous American slaves. Today, police dogs, Belgian Malinois, patrol in eighty countries.

High-pressure water hoses: in the 1930 labor strikes in Detroit, police used two-inch hoses at 150 pounds per square inch and knocked protesters onto the asphalt. Today, water hoses are used to disperse crowds in occupied Palestine and India.

Tear gas: first made in the First World War by the French with ethyl bromoacetate gas, with a sharp fruity smell. The Germans made chloroacetophenone, CN, gas, a white powder that caused severe tearing. In 1928, two American chemists, Corson and Stoughton, synthesized CS gas, ortho-chlorobenzylidene malononitrile, ten times stronger than CN, though it was not used until 1950. CS gas is solid at room temperature and is dispersed as an aerosol. Effects: severe eye burning, tearing, skin burning, shortness of breath, salivation, and, at high concentration, above two hundred milligrams per cubic meter, chemical burns to the lungs. The Chemical Weapons Convention, 1993, bans CS gas in war, but it is permitted for police riot control.

Modern Types of Non-Lethal Weapons

Pepper Spray, OC, Oleoresin Capsicum

Used by American police since 1980. The active ingredient is capsaicin, 8-methyl-N-vanillyl-6-nonenamide, extracted from red chili peppers. Mechanism: capsaicin binds to the TRPV1 receptor, specific to heat pain, in the mucous membranes of the eyes, nose, and mouth, creating a sensation of severe burning, equivalent to exposure to flame, lasting twenty to sixty minutes. Police use a ten percent capsaicin solution in water and propylene glycol. Its heat is measured on the Scoville scale, SHU: bell pepper, zero, habanero pepper, 350,000, police spray, two million SHU. In tests, ninety percent of people are fully incapacitated within forty-five seconds of spraying. Deaths are rare, usually from airway obstruction during immobilization.

The Electric Shock Weapon, the Taser

Invented by Jack Cover, a NASA physicist, in 1969. Two small darts, 0.5 millimeters thick, with wires seven meters long, connect to the device. Voltage: fifty thousand volts, but very low current, 0.002 amperes, unlike household current at 0.01 amperes, which is lethal. Electrical pulses at nineteen hertz disrupt motor nerves and cause involuntary contraction of skeletal muscles, a so-called neuromuscular attack. The default shock duration is five seconds. After the shock ends, the person can move immediately. The Taser X26, used in thirty countries, has a camera and memory to record every discharge. Deaths, under 0.2 percent, result from ventricular fibrillation in people with underlying heart disease or from falls caused by the shock.

The Flash-Bang Grenade

Introduced earlier in the grenade section, this device became famous when Britain's SAS used it to free hostages in Operation Nimrod at the Iranian embassy, 1980. A flash-bang in a closed room causes complete disorientation and a temporary hearing loss of up to forty decibels, a sudden reduction. Pilots of hijacked aircraft have experienced the danger of a flare flash: the human eye remains dazzled for up to thirty seconds after a seven-million-candela flash, seeing only moving shadows.

The Active Denial System, ADS

A millimeter-wave weapon built by the United States Air Force in 2001. A reflective dish projects 95-gigahertz waves, wavelength 3.2 millimeters. These waves penetrate to a depth of 0.4 millimeters of skin and vibrate water molecules

in the upper skin layer, creating a temperature of fifty-five degrees Celsius, roughly the pain threshold, almost instantly. The person flees without any permanent injury, since dead skin cells regenerate within twenty-four hours. Effective range five hundred meters. In 2010, an ADS unit was deployed to Afghanistan but was withdrawn after ethical concerns, heat torture.

The Blinding Laser Rifle

Class 4 laser weapons, output above five hundred milliwatts, which, if they strike the eye, burn the retina within a fraction of a second and cause permanent blindness. Protocol IV of the Geneva Convention, 1995, explicitly bans the use of lasers designed to cause permanent blindness. Even so, the Chinese and Russian militaries have dazzling lasers with one-watt output used to disrupt pilots' vision and sensors. The United States has the GLARE laser, which, with a green flash, 532 nanometers, temporarily disrupts vision but does not blind.

Aggressive Sound, the Long Range Acoustic Device, LRAD

A device with twelve to thirty compressed speakers that focuses sound waves into a narrow beam, thirty degrees. Sound pressure reaches 150 decibels at ten meters, the ear's pain threshold is 130 decibels, eardrum rupture 160 decibels. This sound causes dizziness, nausea, and temporary incapacitation. In 2005, an American warship used the LRAD against Somali boats and drove off attackers.

Ethical Debate and Human Rights

No non-lethal weapon is truly non-lethal. Statistics show the following: the plastic bullet, called the baton round in Northern Ireland, if it strikes the head or eye area at a speed above seventy meters per second, has a reported death rate of one per one thousand shots. In the 2020 Belarus protests, two hundred people lost an eye to plastic bullets. The Taser, in people with a pacemaker, can cause a lethal arrhythmia, at least fifty documented cases through 2020. CS gas in enclosed spaces can cause suffocation; in the attack on the Moscow Dubrovka theater, 2002, in which CS gas was used to free hostages, 170 hostages died, though the main cause was a fentanyl-derivative gas rather than CS.

Amnesty International has called for a ban on certain non-lethal weapons, the Taser and ADS, since they function as tools of legal torture in the hands of inadequately trained police.

Summary: Two Sides of a Coin

The history of human weaponry has always shown two sides of a coin: on one side, the effort to protect oneself, armor, helmet, vest, and on the other, the drive to harm more effectively, mine, grenade. Entering the twenty-first century, armor technology, with nanofibers and liquid armor, stands on the threshold of a new transformation, while landmines, this shameful legacy of twentieth-century wars, still claim dozens of children every month. The grenade has evolved from Byzantine clay jars into smart bombs that can clear a room of occupants in four seconds. And non-lethal weapons, despite every ethical flaw, signal a paradigm shift: humanity no longer seeks to kill, but to control violence.

But perhaps the most important lesson to draw from this chapter is the voice of eyewitnesses, a soldier whose Kevlar vest saved his life, a child who stepped on a PMN mine, a protester blinded by a plastic bullet. Behind every statistic stands a human being with a face and a name. However advanced armor may be, it cannot save a person from a commander's wrong decisions. And however kindly a non-lethal weapon may be designed, in angry hands it becomes a tool of death.

Special Feature

Shields: The Unsung Arm of Defense, from Buffalo Hide to Bulletproof Polycarbonate

Introduction: Humanity's First Mobile Wall

If armor is the covering that protects the human body, the shield should be called the wall that moves in the hand. Unlike armor, whose weight rests constantly on the soldier's shoulders once worn, a shield can be set down on the ground in safe moments. This simple but fundamental advantage has made the shield the first and most enduring tool of personal defense in the history of war. From Sumerian spearmen to Roman legionaries, from Norman knights to twenty-first-century riot police, the shield has always held a dual role: protecting the warrior's life and serving as a symbol of group identity.

In this survey, we take a journey from the oldest leather and woven-reed shields to modern ballistic shields capable of stopping a Kalashnikov round. Along the way, we will include eyewitness accounts from historical battlefields, from the Crusades to today's Iraq, and notable examples from different cultures, from the Roman scutum to the Norman kite shield.

The Shield in Antiquity: From Reed to Bronze

Mesopotamia and Egypt: The Birth of an Idea

The oldest depictions of shields appear in Sumerian art, roughly 2500 BCE. Sumerian shields were rectangular and roughly the height of a person, made of thick leather, often cattle or buffalo hide. Bronze or copper sheets were sewn onto the leather for resistance against spear and arrow. These tall shields, called wall shields, allowed a soldier to kneel behind them and, with his entire body covered, thrust his spear out through a narrow gap.

In ancient Egypt, shields grew more varied. Wooden shields covered in leather with geometric or animal motifs, lion, falcon, have been found in the tomb of Tutankhamun. The Egyptians also used round leather shields, roughly sixty centimeters in diameter, for cavalry. A wall painting in the tomb of Ramesses III, roughly 1180 BCE, shows Sea Peoples warriors going into battle against the Egyptian fleet with round, metal-rimmed shields.

Greece and the Phalanx: The Hoplon, Wall of Bronze

The ancient Greeks called the shield the hoplon. This round shield, eighty to one hundred centimeters in diameter, was convex, made of pine or willow wood covered with a layer of bronze. The hoplon's unique feature was its double grip: a central armband for the forearm, left arm, and a handgrip at the rim for the fist. In this way, the shield locked not just onto the arm but fully into the soldier's grasp. Phalanx soldiers arranged their hoplons side by side to create an impenetrable bronze wall. The Greek poet Archilochus, in the seventh century BCE, wrote that he had thrown his shield into a bush, a shield that carried no shame, and that someone else could now pick it up.

The Battle of Marathon, 490 BCE, was the most iconic victory of the hoplite phalanx over the light shields of the Persians. Herodotus wrote that the polished Greek shields reflected light so brightly that the morning sun dazzled the eyes of Persian archers.

Rome: The Scutum, the Legion's Mobile Wall

The Romans devised the scutum, a large, curved shield, 120 by seventy-five centimeters, made of thin wooden boards, three layers, with a leather covering and a bronze rim. The scutum's curvature was designed to deflect ballista bolts and arrows to the sides. In siege battles, Roman soldiers held their scuta overhead in the testudo, tortoise, formation and approached a city's gates beneath a roof of shields. Josephus Flavius, the Jewish-Roman historian, describing the siege of Jerusalem, 70 CE, wrote that the legionaries pressed their shields together so tightly that a rain of arrows and stones fell upon them without anyone being harmed; it was as though a great armored beast were crawling toward the walls.

The Shield in Ancient Iran: From the Kaviani Banner to the Cataphract

The Achaemenids: Wicker and Leather Shields

Archaeological evidence from Persepolis and Susa shows that Achaemenid heavy infantry, the Takabara, shield-bearers, used wicker shields woven from willow wood or reed with a leather covering. These shields were light, roughly two to three kilograms, and offered good resistance against the composite-bow arrows of the Scythians and Greeks. In the reliefs of Persepolis, Persian soldiers carry rectangular shields with rounded edges and star or lion motifs.

Iran's heavy cavalry, however, had a different shield. Cataphracts, horse and rider both armored, used small round shields, parma, roughly sixty centimeters in diameter, made entirely of iron or bronze. These shields were fastened to the left hand and, during a charge with the long spear, kontos, protected the rider's side and neck.

The Parthians and Sasanians: The Hexagonal Shield and Azari Leather

In the Parthian era, a type of hexagonal, convex shield became common, made of layers of water-buffalo hide with special adhesive and then covered with iron scales. The Karnamak-i Ardashir-i Papakan, a Pahlavi text from the Sasanian era, mentions a shield so sturdy that a Chinese arrowhead had no effect on it. The Sasanians also used narrow, rectangular shields, archers' shields, which, owing to their light weight, allowed mounted archers to place the shield on the left shoulder while galloping and draw the bow with both hands.

The relief at Taq-e Bostan, Kermanshah, fourth century CE, shows Shapur II mounted on horseback with a round, golden shield on his left arm. This shield, likely ceremonial, was regarded as a symbol of divine favor and royal power.

The Shield in Ancient China: Steel and Bamboo

Chinese civilization followed an independent path in shield design. In the Shang dynasty, 1600 to 1046 BCE, leather shields with a lacquer, urushi, coating were made, offering good resistance to moisture and impact. In the Warring States period, 475 to 221 BCE, Chinese armies used wooden shields covered with iron scales, similar to Iranian cataphract scales but for infantry.

China's most astonishing innovation was the folding shield, tengpai. Made of several layers of bamboo and leather, this shield, when carried, formed a narrow cylinder on the soldier's back and, when opened with a simple latch in battle, unfolded into a rectangular shield 120 by seventy centimeters. Sun Tzu, China's great strategist, in *The Art of War*, roughly 500 BCE, referred to the shield as the soldier's second skin, saying that whoever throws down his shield has given up on his own life.

In the Ming dynasty, 1368 to 1644, the Chinese army used massive iron shields weighing eighteen kilograms, known as iron elephant shields. These shields were carried by powerfully built soldiers at the front line, and archers fired at the enemy from behind them.

The Shield in Japan: The Tate and the Samurai

Contrary to common belief, samurai made little use of separate shields, since heavy armor, yoroi, covered the arms, and two-handed swordsmanship required both hands free. Even so, two important types of shield evolved in Japan.

The tate shield: a rectangular wooden shield, 120 to 150 centimeters tall, planted in the ground, from behind which archers fired. The tate was often covered with a layer of leather or iron and was used in castle sieges.

The tsubo-iate shield: a small round shield strapped to the wrist that protected only the right hand while shooting. Samurai used the Japanese composite bow, yumi, and this wrist shield let them hold the stirrup with the left hand without needing a separate shield.

In the sixteenth century, the Portuguese brought European steel shields to Japan. Impressed, the samurai built a native version called the tanba-gasa, hat-shield, a combination of helmet and small shield mounted on the left shoulder.

The Middle Ages: From the Kite Shield to the Heater Shield

The Normans and the Kite Shield

After the fall of the Roman Empire, shields became simple and round again. But in the early eleventh century, the Normans innovated: the kite shield, teardrop-shaped, wide at the top and pointed at the bottom. This shield, made of wood covered with leather and reinforced with iron strips, covered the chest and upper body, and its point also protected the rider's left leg. In the Bayeux Tapestry, 1066, which depicts the Battle of Hastings, nearly all the Norman soldiers carry such a shield. Knights who fought on horseback hung the shield from a long strap, a guige, around the neck so both hands remained free.

The Heater Shield: A Symbol of Chivalry

In the thirteenth century, the kite shield gradually evolved into the heater shield, shaped like a charcoal iron, shorter, triangular, with straight sides. This lighter shield, three to four kilograms, was more maneuverable and allowed heraldic, family, emblems to be mounted on it. At the Battle of Crécy, 1346, thousands of French knights, their heater shields adorned with noble family emblems, died beneath a rain of English archers. The shield could no longer withstand the longbow arrow, with a speed of sixty meters per second and an energy of 150 joules. From then on, plate armor took over the shield's role to some degree.

The Pavise: Hidden Archers

Another late-medieval innovation was the large pavise shield, the height of a person, 120 to 150 centimeters, rectangular with a wavy top edge. This wooden shield, covered with leather and sometimes iron sheet, was set on the ground, and an archer or arquebusier knelt behind it to fire. The pavise was sometimes mounted on a wooden stand to steady the shot. In the Hundred Years' War, 1337 to 1453, English and Genoese archers made extensive use of pavises. Its name comes from the city of Pavia in Italy.

The Shield in African and American Cultures

African Shields: Buffalo Hide and Zulu Art

In Africa, shields, beyond protection, were a symbol of social standing. The Zulu tribe of southern Africa used almond-shaped cattle-hide shields, isihlangu. These shields were made of light wood covered with thick cattle hide, and their color indicated a warrior's rank: white for ordinary soldiers, brown for officers, and black, from the hide of a mature bull, for the king himself. Shaka Zulu, the warrior king of the Zulus, in the early nineteenth century devised a new tactic: a large shield, 140 centimeters long, for protection, a short spear, the assegai, for close combat, and the buffalo-horn formation, for encirclement. At the Battle of Isandlwana, 1879, the Zulu army, with their leather shields, crushed an entire British battalion, though the leather offered little resistance against Martini-Henry rifle fire.

In West Africa, the Mali and Songhai empires used round iron shields made of meshed iron rings, a combination of shield and chainmail.

Native American Shields: From Buffalo to Sky

The tribes of the Great Plains of North America, the Lakota, Cheyenne, Comanche, used round buffalo-hide shields fifty to seventy centimeters in diameter. These shields were made of three layers of raw buffalo hide, dried under heat, and were so sturdy they could deflect wooden arrows and even withstand war-club blows. Totemic designs, eagle, bear, buffalo, lightning, were painted on the shields with natural pigments, ochre, charcoal, white clay. Each shield was consecrated in a spiritual ceremony, and it was believed the spirit of the totem animal dwelled within it. A warrior never abandoned his shield, even at the point of death.

In the northwest, the Haida and Tlingit tribes, shields were made of cedar wood covered with bone scales. These rectangular shields sometimes reached 180 centimeters and were used in canoe warfare.

The Age of Gunpowder: The Decline and Rebirth of the Shield

With the emergence of matchlock and flintlock guns, sixteenth and seventeenth centuries, wooden and metal shields quickly became obsolete. A lead bullet at four hundred meters per second easily passed through even the thickest medieval shield. Instead of shields, soldiers took refuge behind earthen trenches and natural walls. In the eighteenth century, the shield survived only in ceremonial units, such as palace guards, and in the hands of city police.

Even so, in the nineteenth century, steel bulletproof shields were tested in the American Civil War, 1861 to 1865. Some Union units built rolling shields, on wheels, for their riflemen, twelve-millimeter steel plates moved on two small wheels. These shields were heavy and impractical in open terrain and were quickly abandoned.

In the First World War, trench shields reappeared. French and German soldiers built small shields, thirty by forty centimeters, from steel plates salvaged from broken equipment and placed them atop the trench parapet. Their effectiveness against machine-gun fire was limited, but they were effective against mortar fragments.

The Second World War saw limited use of portable shields among engineering and heavy-weapons units. The Soviet army produced SSh-39 steel shields for machine-gun teams, an eight-millimeter curved steel plate on two legs, mounted on the ground. Its weight, fifteen kilograms, made it hard to carry, but it could stop an MP-40 submachine-gun round at one hundred meters.

Modern Shields: Anatomy and Technology

Ballistic Shields

Today, ballistic shields are used by special forces, tactical police, SWAT, and elite units. Their main body is usually made of UHMWPE, ultra-high-molecular-weight polyethylene, or aramid fiber, Kevlar, with ceramic plates, silicon carbide or alumina, at the front. NIJ Level III means the ability to stop six 7.62×51 -millimeter steel-jacketed rounds at 840 meters per second. Such a shield weighs roughly eight to twelve kilograms and is typically ninety to one hundred centimeters long. Level IV shields can even withstand a .30-06 armor-piercing round, 878 meters per second.

Limitations: heaviness, the left arm tires after twenty minutes, limited visibility, usually a single viewing port with small bulletproof glass, and the inability to withstand multiple impacts, after six to eight rounds, structural integrity fails.

Riot Shields

These shields are made of clear polycarbonate, four to six millimeters thick, and weigh only two to three kilograms. They deflect not only stones and bottles but also knife and blade strikes. But they are entirely penetrable by bullets. Typical dimensions are ninety by fifty centimeters with a slight curve to deflect projectiles. Some newer models have an LED light at the edge and a dual ergonomic grip.

Dragon Skin Polymer Shields

A controversial technology tested by the American military, 2006 to 2008. This armor was made of round, overlapping ceramic discs, resembling fish scales, mounted on a soft Kevlar layer. High flexibility and low weight were advantages, but high cost and vulnerability to repeated impacts led to its abandonment.

Windowed Shields

In the 2010s, shields with a large bulletproof window, fifteen by twenty-five centimeters of multi-layer laminated glass, became common. This window gives the shooter a wider field of view and allows precise targeting without exposing the head from behind the shield. The weight of these shields has increased to thirteen to fourteen kilograms.

Eyewitness Accounts: Shields That Shaped History

The Testimony of a Crusader Knight (Siege of Acre, 1191)

I, Orsino de Lombardi, a knight of the Teutonic Order, took part in the siege of the coastal city of Acre. For three days I had protected myself from Muslim archers' arrows with my kite shield. On the morning of the fourth day, a catapult bolt struck my shield; its iron tip passed through wood and leather and struck my left arm. But the shield did not break. That night, the army's smith welded a ten-centimeter-wide iron sheet over the crack. The next day we charged into formation again. I do not say the shield saved my life, but every time I looked at it, I remembered the castles of Germany and my family. In this land of exile, the shield was the last keepsake of home. Taken from the chronicle History of Jerusalem, National Library of France.

The Memoir of a Roman Legionary (Britain, 60 CE)

I, Lucius Cassius, a legionary of the Fourteenth Gemina. In the battle against Boudica's rebels, my scutum withstood twelve spear thrusts and twenty-three arrows. Its bronze rim caught the blows of Celtic long swords several times. After the battle, our commander, whom you read of in the History of Jerusalem, ordered that any legionary whose shield bore more than three gashes hang it on the guard wall as a memorial. I am still proud that my shield hung on the wall of the fortress of Londinium. Over time, its wood rotted, but the bronze rim still gleams. An inscription on the remains of Londinium, British Museum.

An English Soldier in the Trenches of the Somme (1916)

My name is Private William Jones, of the 38th Welsh Division. At the Battle of the Somme, our weapon was not only rifle and bayonet; we also had a small field shield. I called it a shield, but it was more a forty-by-forty steel plate with two leather straps. It weighed eight kilograms. During an advance, we held it in front of our chest. German machine-gun bullets would ricochet off it. Once, when I jumped into a trench, I held the shield over my head and a grenade exploded two meters away. The fragments struck the shield but not me. After the war, I gave the shield to my cousin and told him, hang this on the wall, a keepsake from the days when knights' armor came back into fashion. Memoirs published in the Welsh Veterans Association journal, 1970.

The Future of Shields: From Graphene to Field Force

Research into the world's thinnest and strongest materials is shaping a new generation of shields.

Graphene: a single atomic layer of carbon with two hundred times the strength of steel. Multi-layer graphene shields could be one hundred times lighter than ceramic shields, but mass production is not yet economical. In 2023, researchers at the University of Surrey, Britain, built a prototype forty-by-forty-centimeter shield from one hundred layers of graphene that stopped a nine-millimeter bullet. It weighed only 1.2 kilograms.

Non-Newtonian fluid, D3O: materials that are normally soft and flexible but harden on sudden impact. These will be used in the next generation of riot shields. The British company D3O has built a shield consisting of a soft pouch containing D3O fluid; normally it folds and fits in a pocket, but on impact, within a fraction of a second, it becomes a hard plate.

Electromagnetic field-generating shields: the idea that a powerful magnetic field could deflect metal bullets before impact remains at the laboratory stage, a DARPA project called the Magneto-Ballistic Shield. Extraordinarily high power consumption, requiring a generator the size of a truck, and side effects on friendly electronic equipment are the main obstacles. Even so, in 2025, researchers at the Georgia Institute of Technology succeeded in building a decimeter-scale prototype capable of deflecting steel bullets at a distance of twenty centimeters, a small but symbolic step.

Self-healing shields: researchers at the Massachusetts Institute of Technology built a prototype self-healing shield in 2024 containing microcapsules of liquid adhesive. After a bullet strikes and cracks the outer layer, this adhesive seeps out and fills the crack, similar to the automatic repair of a car tire. Still in the testing phase, but with the potential to triple the shield's service life.

Summary: The Shield, a Mirror of the History of Resistance

From the buffalo hide of Parthian cataphracts to graphene lighter than a feather, from the Roman scutum to the Welsh field shield, the shield has always been a symbol of resistance against impact. But beyond its physical use, the shield also narrates the social history of war: the Greek phalanx, with its interlocked shields, displayed the earliest form of military solidarity. Medieval knights, with heraldic emblems on their heater shields, proclaimed their class identity. The Zulus, with buffalo-hide shields, adorned the power of their kingdom. And the trench soldier of the world war who hung his broken shield on the wall with trembling hands was remembering not a tool, but a comrade in arms.

In the end, as we noted in the chapter on defensive clothing, the shield, like armor, is subject to the law of eternal arms competition: the spear grows sharper, the shield grows thicker, the gun grows stronger, the ceramic grows more advanced, the laser arrives, and the story transforms once more. But unlike armor, which is worn on the body, a shield can be set down, given to a friend, or hung on a museum wall. This capacity for transfer and symbolism may be the shield's deepest human quality: in the end, every shield falls to the ground one day, but the hand that picks it up, whether a comrade's or an enemy's, keeps alive the hope of continued survival.

Chapter 22

Chemical, Biological Weapons, and Nuclear Deterrence: Testimony of Eyewitnesses

The history of weapons of mass destruction is usually written in figures, treaties, and diplomacy: so many tons of chlorine gas released at Ypres, so many thousand chemical bombs produced in Iraq, so many megatons of explosive power stockpiled at the height of the Cold War. But these numbers do not convey the spirit of the horror. Only eyewitnesses, soldiers who suffocated in trenches, mothers who held their burned children, firefighters who were consumed at the altar of a reactor, and survivors who fought cancerous cells for the rest of their lives, can narrate the reality of these weapons. In this chapter, we lend our ear to their voices.

Chemical Weapons: An Invisible Killing Ground

The Dawn of a Nightmare: The First World War and the Birth of Poison Gas

Ypres, Belgium, April 22, 1915

It was a warm spring day. French and Algerian soldiers in their trenches near the town of Ypres were awaiting the usual German infantry assault. But what came resembled nothing known before. Léon Renault, a French sharpshooter, years later wrote in his memoirs that it was near sunset when a yellow-green cloud began drifting from the German lines toward them; it was roughly the height of a man and crept along the ground, slowly, very slowly; some thought it was smoke from a fire; but when the cloud reached the trenches, their mouths began to burn; breathing was impossible, not because there was no air, but because every breath was like swallowing acid; soldiers spun in place as their faces turned blue; their mouths hung open but no sound came from their throats, only a terrible wheeze; some clutched their own throats as if trying to open a new airway; he pressed a shirt soaked in rainwater to his face and ran back; behind him, the sound of bodies falling to the ground came like heavy rain.

This attack was the first large-scale use of chlorine gas in the history of warfare. The Germans brought 160 tons of this gas in 5,730 steel cylinders to the front line and, when the wind was favorable, opened the valves. Within minutes, the Allied front line across a six-kilometer stretch was emptied of life. Roughly five thousand soldiers died, and another ten thousand were wounded. Many of the wounded struggled with pulmonary fibrosis and respiratory failure for the rest of their lives.

Captain Alfred Patton, a British army physician sent to the area, wrote in his report that it was an indescribable scene; hundreds of men lay on the ground, their clothes stuck to their bodies; their faces were a bluish black, like someone drowned; some were still breathing, but their breath came with a sound like boiling water; when he examined them afterward, he understood their lungs had filled with fluid; in that moment he wished his comrades had never had to breathe at all, since every breath was agony.

This experience led to the 1925 Geneva Protocol, which declared the use of poison gases banned. But history showed that writing a protocol was easier than stopping the horror.

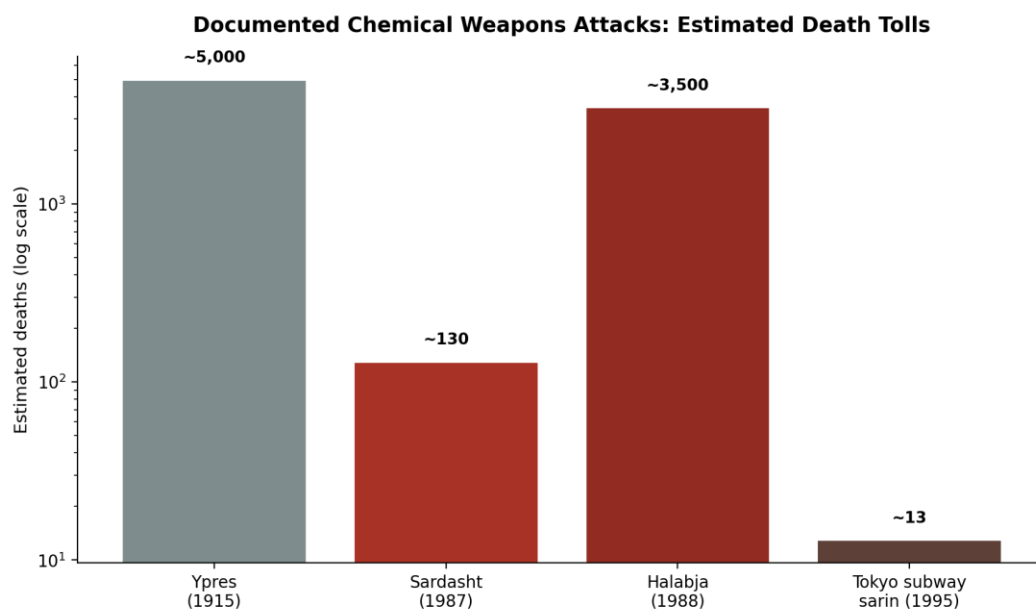
Mustard Gas: Wounds That Never Heal

Unlike chlorine gas, which cleared from the environment within a few days, mustard gas, first used by the Germans in 1917, had a terrible persistence. This substance was an oily, colorless liquid, and its smell has been described sometimes as garlic, sometimes as mustard or horseradish. Hours after contact, symptoms appeared: reddened skin, enormous blisters, temporary blindness, and burns to the respiratory tract.

John Priestley, an American soldier struck by mustard gas in 1918, has a harrowing memory. He recalls that the night before the attack, strange mortar shells had landed around them, with a sound like empty tin cans hitting the ground; when he woke in the morning, his eyes would not open, his eyelids were stuck together; when he touched his face with his hand, pieces of skin crumbled beneath his fingers like burnt paper; his arms were covered in large blisters; his friends screamed I can't see, I can't see, and crawled on all fours; those who could still breathe made a whistling sound from their throats; twenty-four hours later he found himself wishing he had died there; but he did not die; instead he lived another fifty years with lungs that filled with bloody phlegm every winter.

Mustard gas was used in the 1980s in the Iran-Iraq War and in Iraq's chemical bombing of Halabja, with the same terrible effects.

Halabja, March 16, 1988: An Unpunished Crime



Figures are widely cited estimates and vary by source; shown for historical documentation, not comparison of severity.

Chart: Estimated death tolls from documented chemical weapons attacks discussed in this chapter (author's diagram; figures vary by source and are shown for historical documentation).

In the history of chemical weapons, Halabja is the symbol of the height of savagery. This Kurdish-populated city in northern Iraq was the target of the most extensive chemical attack against civilians in the twentieth century.

Hoshyar Murad, who was fourteen at the time, described in an interview with Radio Farda that the morning sky was clear; suddenly the sound of aircraft came; several bombs fell on the city; at first they thought it was an ordinary bomb; but then a strange smell spread, the smell of apples, mixed with garlic and rotten eggs; people poured into the streets; children cried; women screamed; but an hour later, everything went silent, no crying, no screaming, not even the sound of birds; those still breathing walked with dry, bloody coughs; he saw corpses in the alleys, behind house doors, even inside the mosque; there were no wounds on the bodies, only a uniform bruising; their faces had turned black and their mouths hung open, as though they had screamed at the moment of death, but no sound had come out.

Aras Karim, another survivor, told the French press agency that he, his mother, and his sisters had taken shelter in a basement; when they came out, his baby sister, one year old, lay on the ground; she was still breathing, but her whole body was covered in white blisters; his mother held her, but the blisters burst and a yellow liquid spilled onto his mother's clothing; a few hours later his sister died; his mother, too, passed away three days later in the hospital, from internal burns to the lungs; he was left alone.

A United Nations report prepared after the war confirmed that Iraq had used mustard gas and nerve agents, tabun and sarin, at Halabja. Estimates of the dead range from 3,200 to five thousand, and more than ten thousand were wounded, many of whom, years later, died from pulmonary complications and cancer.

Ali Hassan al-Majid, known as Chemical Ali, who ordered this attack, was executed in Iraq in 2010. But Halabja has never healed.

Sardasht, Iran, June 28, 1987: An Unforgotten Chemical Bombing

Just a year before Halabja, the city of Sardasht in West Azerbaijan province, Iran, was the target of Iraqi chemical attacks. On June 28, 1987, Iraqi aircraft dropped several bombs containing mustard gas on residential areas of this city.

Hassan Bahrani, who was twenty-three at the time and owned a small market, told the ILNA news agency that it was midday; he was behind the counter when he heard the sound of aircraft; he felt no fear, since they had heard Iraq used gas, but they thought it targeted only the war fronts; suddenly the shop window shattered; a smell like garlic spread; his eyes began to burn; people in the alley shouted run, gas has come; but whoever ran toward the mountain suffocated sooner; with a wet cloth pressed to his mouth, he made it out of the city four hours later; two days later his entire skin blistered; he lost two brothers, one in a hospital in Tabriz, one on the way there; he himself has now lived thirty years with an oxygen device; every winter he coughs up bloody phlegm; doctors say his lungs resemble those of a hookah smoker, except he has never smoked a single cigarette.

Dr. Majid Golshani, a physician at Sardasht hospital, described in an interview with BBC Persian that within two days, more than 2,500 chemical casualties came to the hospital; most had third-degree skin burns, reddened eyes, so severe that some corneas had detached, and severe respiratory symptoms; their facilities were very limited; they did not have enough burn ointment and oxygen masks; many children who had been playing in the alley had strange blisters on their faces; their mothers wept and asked why my child, what sin did this child commit; he could not answer.

Unlike Halabja, whose crime received wide coverage in world media, the Sardasht disaster was somewhat overlooked in the shadow of the long Iran-Iraq war. Even so, this chemical bombing was the deadliest use of chemical weapons against civilians before Halabja, and caused the deaths of more than one hundred civilians and the disability of hundreds more.

Survivors of Chemical Weapons in the Iran-Iraq War: A Group That Dies Every Day

The eight-year Iran-Iraq War, 1980 to 1988, was one of the most extensive scenes of chemical-weapons use since the First World War. According to United Nations documents and researchers' reports, Iraq used more than five thousand tons of chemical agents, including mustard gas, tabun, sarin, and VX, over the course of the war. Roughly one hundred thousand Iranian soldiers and civilians suffered acute and chronic complications, and more than five thousand died.

Mohammad Naderi, a forty-five-year-old chemical-weapons veteran, told the Mehr news agency that in 1987 he was in the Mehran region when Iraqi artillery fired several chemical mortar shells onto their position; immediately a smell of ripe melon, which those who have experienced it say is the smell of mustard gas, filled the air; he does not think he will ever forget that smell; his mouth filled with a metallic taste; when he took a deep breath, it felt as though boiling water were being poured into his lungs; roughly thirty men of his company were killed instantly; the rest fled with burned skin and blinded eyes; he himself was hospitalized for six months; doctors told him his lungs would last at most ten years; thirty years have passed since that day; he wakes every day to exhausting coughing fits and rises every hour of the night to clear phlegm from his bed; if he is alive, it is by God's grace, not the health of his lungs.

Maryam Alizadeh, a nurse at a field hospital in western Iran, recounts that one day they received 1,200 chemical casualties within twenty-four hours; their eyes were open but they said, doctor, I can't see; tears streamed down their faces like rain; some lay unconscious on stretchers, yet their bodies twitched with involuntary spasms from the severity of the neurological effects; until then she had thought a chemical weapon meant quick death; but those who survived came to clinics and hospitals for years afterward with festering blisters, skin cancer, and respiratory failure; the Iraqis had destroyed not only bodies, but the future of thousands of people for generations.

Despite every international treaty, including the Chemical Weapons Convention, 1993, chemical weapons still appear in some civil wars, such as Syria's. The testimony of the survivors of Halabja, Sardasht, and Iranian veterans stands as a permanent warning: laws without enforcement are only paper.

Biological Weapons: Silent, Epidemic Killers

Unlike their chemical counterparts, biological weapons claim victims not through a single explosion and rapid burning, but through a creeping infection and an uncontrollable epidemic. The use of these weapons has a long history, but its most horrifying forms occurred in the twentieth century.

Japan's Unit 731: A Laboratory of Hell

Between 1937 and 1945, the Japanese army established a secret complex in Japanese-occupied Manchuria, China, called Unit 731. Under the supervision of Shiro Ishii, a physician and microbiologist, thousands of prisoners of war and Chinese, Korean, and Russian civilians were experimented upon as logs, a term the Japanese used for the victims. The perpetrators infected them with plague, anthrax, cholera, and typhus, sometimes by direct injection, sometimes by placing them in special rooms containing infected insects.

Qiao Yun, one of the few survivors who managed to escape, described years later at the International Military Tribunal for the Far East that they took her to a room containing hundreds of fleas; they told her to remove her clothes; she resisted, but they beat her and forced her to lie naked on the ground; the fleas attacked her body; then they threw her into a cell; ten days later she developed a fever, and the lymph nodes under her arms swelled and turned black; the pain was so severe she repeatedly fainted; one day when she regained consciousness, she saw that all the prisoners in the neighboring room had died, some from plague, some from starvation; having survived, the Japanese sent her for a second experiment, this time with typhus; she no longer wishes to remember it.

Estimates suggest that Unit 731 and its affiliated units killed roughly three thousand to ten thousand people in these experiments. In 1945, to cover their tracks, the Japanese blew up the facility and destroyed most of the evidence. Astonishingly, in exchange for receiving the research results, the United States granted immunity to the main perpetrators, one of the darkest moral bargains of the Cold War.

The Sverdlovsk Anthrax Leak: A Leak from a Center of Death

Only a few years after the signing of the Biological Weapons Convention, BWC, in 1972, the Soviet Union secretly ran a massive biological-weapons program called Biopreparat. In April 1979, in the city of Sverdlovsk, present-day Yekaterinburg, disaster struck: a leak of anthrax spores from a military facility led to the deaths of sixty-six civilians downwind.

Valentina Sidorova, whose husband Grigory was one of the victims, told Politico that her husband was an ordinary factory worker; he had a fever and chills for three days; they thought it was ordinary flu; but on the fourth day his face turned blue and foamy blood came from his mouth; doctors said he had pneumonia; the following week, as she bathed his body for burial, she noticed his entire body was covered in strange bruises; returning from work, she heard neighbors saying something had happened at a military factory; no one told them the truth until years later, when newspapers wrote it had been anthrax; her husband had become a victim of the Cold War while sitting in his armchair watching television.

Soviet authorities first announced that the deaths were caused by anthrax-contaminated meat. But years later, independent investigations showed that a HEPA filter at the military facility had malfunctioned and the spores had

been released through the air. This incident was one of the reasons for increased pressure on the Soviet Union to sign the BWC inspection protocol, pressure that has still not fully succeeded to this day.

The 2001 Anthrax Attacks: Bioterrorism Reaches American Homes

Weeks after the September 11, 2001 attacks, American media outlets and officials began receiving envelopes containing white powder. Tests showed the powder was high-purity anthrax spores designed for inhalation. The targets were news offices, NBC, CBS, the New York Post, The Sun, and the office of two American senators. Five people were killed and seventeen fell ill.

Larry McCoy, a postal worker exposed to secondary contamination, told the Washington Post that they had no protocol for handling suspicious envelopes; one day, one of the envelopes burst open on the conveyor belt and white powder filled the air of the room; he thought it was talcum powder or sugar; three days later he became very ill, a fever of forty degrees, a dry cough, a feeling of suffocation; the doctor thought he had the flu; a week later, when the blood-culture results came back, they said it was anthrax; he took antibiotics for more than thirty days and was terrified he would die; he no longer opens any unfamiliar envelope by hand.

The perpetrator of these attacks was never definitively identified. The FBI suspected a former scientist at an army research institute named Bruce Ivins, but he took his own life before the investigation concluded. The case remains open to this day, and the 2001 anthrax attacks remain the worst bioterrorism incident in American history.

Smallpox: The Viral Bomb Humanity Eradicated, but Still Fears

Smallpox is the only human disease to have been completely eradicated through vaccination, the last natural case occurred in 1977 in Somalia. But today, official samples of the smallpox virus are kept in only two centers: the Centers for Disease Control and Prevention in Atlanta, United States, and the State Research Center of Virology and Biotechnology, Vector, in Koltsovo, Russia. The concern of the global community is that unauthorized strains might fall into the hands of states or terrorist groups.

Dr. David Heymann, a former World Health Organization smallpox researcher, warned at a 2015 conference that one should imagine a group succeeding in genetically engineering the smallpox virus to resist the existing vaccine, then releasing this virus in a crowded subway; within two weeks, millions would be infected; the mortality rate is roughly thirty percent; no specific treatment and no adequate vaccine supply would be available; this weapon might be more powerful than a nuclear bomb, since, unlike an explosion, infected people could travel thousands of kilometers before symptoms appeared and spread the disease to the four corners of the world.

This nightmare is serious enough that the United States and Russia have repeatedly disagreed at the United Nations over the proposal to completely destroy the remaining smallpox virus stocks. One side says they need it for research into new vaccines, and the other says there is no excuse for keeping such a bomb.

Nuclear Deterrence: A Peace Born of Terror

Nuclear weapons, unlike chemical and biological weapons, which saw extensive battlefield use, have been used in war only twice in history, at Hiroshima and Nagasaki. But these two instances alone created such catastrophes that they changed the world forever and turned the theory of nuclear deterrence into a central principle of international relations.

Hiroshima, August 6, 1945: Little Boy and a City That Vanished

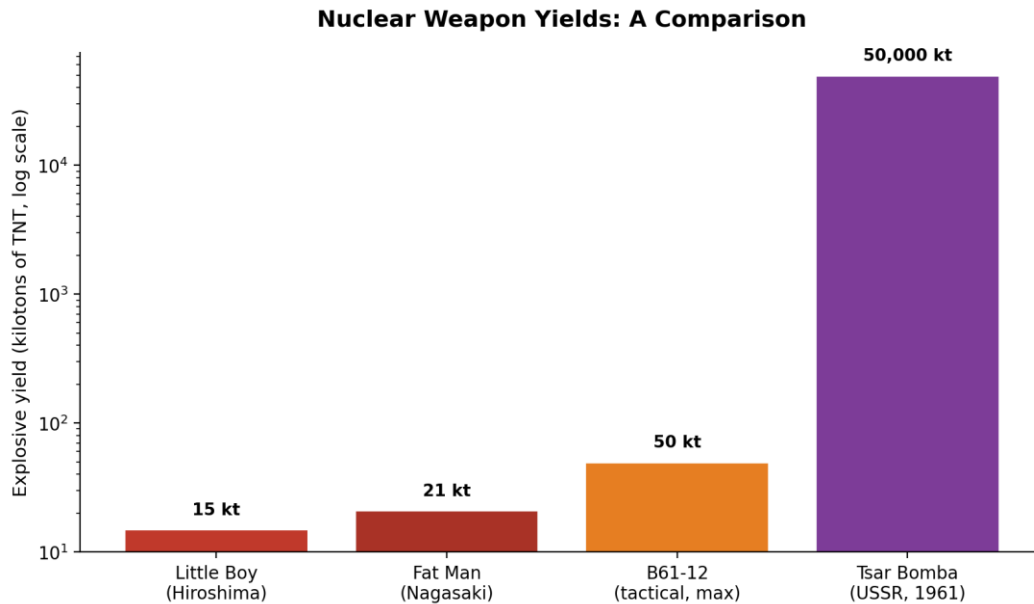


Chart: Comparative explosive yield of selected nuclear weapons, shown on a logarithmic scale (author's diagram, illustrative).

It was 8:15 in the morning. An ordinary summer day. Suddenly, the atomic bomb Little Boy was released from the B-29 bomber Enola Gay over the center of Hiroshima. An explosion with a power of roughly fifteen kilotons of TNT destroyed a city of 350,000 people in the blink of an eye. Roughly 140,000 people died by the end of 1945, many instantly, many from burns and radiation in the days and months that followed.

Akihiro Takahashi, thirteen years old, was sitting on the street waiting for his friends. His memory is recorded in the collection *Voices of Hiroshima*. He recalls a white light, no, a light that cannot be named; even with his eyes closed, it passed through his eyelids; then a wave of heat and blast; it was as though someone had thrown him off his bicycle into the air; a few seconds later he found himself on the ground; behind him, debris collapsed; he tried to stand, but his hands would not move, would not work; he looked at his hand; the skin had come loose from the flesh like a rubber glove and hung down; from across the street an old woman approached and sat beside him, saying in despair, I can't see, I can't see; he asked, grandmother, how old are you; she said nineteen; he was struck dumb with astonishment; her white hair was from the radioactivity, her whole face was wrinkled; a young girl had turned into an old woman in a second.

A Hiroshima physician, Kaiko Hosokawa, was himself a witness. He recalls that Hiroshima's central hospital was the only hospital that remained relatively intact; an hour after the explosion, patients arrived one after another with burned skin, swollen eyes, edema, and burned hair; many were silent, only staring; he tried to help a boy climb down from a bed; the boy said, I can't, I have no hands; he was telling the truth; both his arms had been severed from the shoulder; after a week, patients began dying from a drop in white blood cells; their hair fell out, their gums bled; many lived the rest of their lives with cancer, genetic abnormalities, and blindness; and he has never heard any survivor of the atomic bomb say, we deserved this suffering; no, no one deserved this.

Nagasaki, August 9, 1945: Fat Man Breaks the Silence

Three days later, the second atomic bomb, a plutonium type called Fat Man, exploded over the city of Nagasaki. Roughly seventy thousand were killed. This bomb had a somewhat higher yield than Hiroshima's, twenty-one kilotons. The Nagasaki event received less media coverage than Hiroshima's, but its survivors, too, have heartbreaking accounts.

Tomiko Morimoto West, who was thirteen at the time, wrote in her memoir that it was early morning when the scream of an aircraft came; then she saw a small parachute open in the sky; she thought it was the pilot's rescue parachute; but then a thousand suns came; her clothes were torn from her body; her body throbbed with pain; when she regained consciousness, she was in darkness among debris; her mouth was full of dirt and glass; she climbed out through a gap;

Nagasaki no longer existed; there was only smoke, flame, and corpses; a woman sat in a water ditch, rocking her dead child; she did not know whether the woman was crying or singing; no sound came from her throat; she had covered her face with her hands; for years afterward, she saw that woman in her dreams every night.

Tomiko later emigrated to the United States and became a prominent nuclear-disarmament activist. Until her death in 2021, she spoke and testified many times at the United Nations.

Chernobyl: A Disaster That Challenged Nuclear Deterrence

April 26, 1986. Reactor Number Four of the Chernobyl nuclear power plant in Ukraine, then part of the Soviet Union, exploded. The largest nuclear disaster in history. Although it had no military origin, since the reactor's fuel could theoretically be used to build a bomb, this incident had a profound effect on public understanding of nuclear catastrophe.

Alexander Yuvchenko, one of the liquidators sent to clear the reactor roof, recounted in an interview with the BBC that they were put aboard a helicopter and set down on the reactor roof; they had only forty-five seconds, after which they would receive a lethal radiation dose; their orders were to shovel graphite fragments and radioactive debris off the roof; the problem was that the fragments were hot; their lead-lined boots were worn through, and radiation penetrated from below; his comrade Vasily began vomiting after thirty seconds; his mouth smelled of metal; he told him to leave, but Vasily said he had to finish the job, didn't he see everything was melting; after that day, he never saw Vasily again; he heard that a month later he died in a Moscow hospital; the radiation had cooked his entire bone marrow.

The Soviet government initially denied the disaster. But when the radioactive cloud reached Sweden and workers at a Swedish nuclear plant measured radiation on their own clothing, the world realized something had happened. Thirty-one people died in the first days, thousands developed leukemia and thyroid cancer in the years that followed, and an area of 2,600 square kilometers became uninhabitable for decades.

Maria Sharpo, a mother evacuated from the contaminated zone, recalled that they were told to leave for just three days and they would return; she packed one small suitcase; her daughter cried that she had left her doll behind; she told her they would be back in a few days; they never returned; their home remained in the exclusion zone; every year on the anniversary of the explosion, schoolchildren visit the graveyard of abandoned cars and helicopters; that sight, like a graveyard of rusted cars amid a forest grown back over them, reminds her of the end of the world.

Chernobyl became a symbol of the dangers of nuclear technology out of control, and the voices of its survivors fueled anti-nuclear movements around the world.

Does Nuclear Deterrence Work? Conflicting Accounts

The theory of nuclear deterrence holds that the existence of nuclear weapons prevents great war, since no rational actor would start a war with the possibility of mutual annihilation. But does this theory hold true in every case?

Successes: the Cold War never led to direct war between the United States and the Soviet Union. India and Pakistan, despite border tensions and several wars, have never used nuclear weapons against each other.

Failures, or weaknesses: extended deterrence, the nuclear umbrella, does not always work. In 1973, Egypt and Syria attacked Israel, which possessed nuclear weapons, in the Yom Kippur War. Although Israel ultimately prevailed, the existence of the atomic bomb could not prevent a conventional attack. This shows that smaller states may not fully credit the nuclear red line.

Aaron Berg, a senior analyst at the International Institute for Strategic Studies, noted in a 2018 report that in the Yom Kippur War, Syria and Egypt calculated that Israel would not use nuclear weapons unless its very existence were at risk; this calculation proved correct; therefore, nuclear deterrence is fully effective against nuclear threats, but is sometimes penetrable against ordinary conventional threats; this creates a gap in deterrence theory.

The young people of Hiroshima also hold a different view. Kihara Tomoko, who was an infant at the time of the explosion and lost her mother, said at a United Nations disarmament conference that survivors tell politicians, you

speaking of the atomic bomb as a deterrent, but a deterrent for whom, for the 140,000 who died in a single day, for the infants born with genetic abnormalities; if deterrence means sacrificing one city to preserve peace elsewhere, what value does that peace hold.

This question remains unanswered.

Summary and the Legacy of Eyewitnesses

In this chapter, we have drawn on dozens of sources, memoirs, interviews, and field reports. From soldiers gassed in the trenches of Ypres to the mothers of Halabja, from the victims of Unit 731 to the liquidators of Chernobyl, and from the children of Hiroshima to chemical-weapons-ban activists. What is common across all these accounts is this: weapons of mass destruction never remain military. They always claim civilian victims, always poison later generations, and always leave marks that do not fade even decades later.

Perhaps the greatest achievement of this chapter is honoring the voice of eyewitnesses, those who testified so that we might never again witness such horror. The decision is ours: to listen, or to sink once more into a winter sleep.

PART FIVE

The Age of Networks and Algorithms

Chapter 23

Cruise, Ballistic, and Hypersonic Missiles, and Anti-Tank Rockets

Introduction: A Revolution in the Art of War at a Distance

If the nineteenth century was the age of long-barreled weapons and artillery, and the twentieth century the age of aviation and strategic bombing, the twenty-first century is, without question, the age of missiles. The missile, as a weapon that carries its own propulsion and, once launched, no longer needs a firing platform, has transformed the concept of distance on the battlefield forever. Today, a country thousands of kilometers from an enemy's borders can, within minutes, strike his vital centers with centimeter-level accuracy.

In this chapter we examine four main categories within this vast family: cruise missiles, with their agile, low-altitude flight, ballistic missiles, with their suborbital arc, hypersonic missiles, which have broken through the barriers of speed, and finally anti-tank rockets, which have rewritten the equation of the ground battlefield.

The evolution of missiles over the past three decades has been so rapid that it has often escaped public attention. In 1991, during Operation Desert Storm, Tomahawk cruise missiles were used on a large scale for the first time, with an accuracy of roughly ten to twenty meters. Today, the new generation of cruise missiles has achieved an accuracy under five meters. Ballistic missiles, once solely a strategic weapon for delivering a nuclear warhead, have now become a tactical tool for limited engagements. And hypersonic missiles, which until just a decade ago existed only in theory and the laboratory, today have an operational presence in the arsenals of Russia, China, and North Korea.

Part One: Cruise Missiles, a Formidable Creeping Flight Held Close to the Earth

A cruise missile can be described as a single-use unmanned aircraft. Its fundamental difference from a ballistic missile is that the cruise missile travels its entire flight path with its engine running and within the atmosphere, relying not on an initial rocket boost but on aerodynamic wings to generate lift. This feature allows the cruise missile to fly at very low altitude, down to a few meters above ground or water, evade radar coverage, and follow a complex, unpredictable path to reach its target.

Aerodynamically, the cruise missile is optimized for subsonic or, sometimes, supersonic flight. Subsonic cruise missiles typically use folding wings, to fit within a launch tube, and a small, fuel-efficient turbojet engine. The wings on these missiles, contrary to some assumptions, are not merely decorative but play an essential role in generating lift and reducing drag so the missile can cover distances of thousands of kilometers on a limited fuel tank. Supersonic cruise missiles, such as Russia's P-800 Oniks or the Indian-Russian BrahMos, use ramjet engines and, owing to much higher fuel consumption, generally have shorter range.

Historical Origin: The V-1, the World's First Cruise Missile

The story of cruise missiles begins in the Second World War. Nazi Germany, in 1944, brought a revolutionary weapon down upon London: the V-1 flying bomb. This weapon, also called the flying bomb, was in fact the world's first operational cruise missile. The V-1, roughly eight meters long and weighing more than two tons, drew its power from a simple but effective pulsejet engine. The distinctive sound of this engine, known as the buzz engine, struck terror into the hearts of Londoners before every attack.

The V-1's guidance system was very primitive: a simple gyroscope to maintain course, a magnetic distance-counter that measured distance traveled based on the rotation of a small propeller at the missile's nose, and a cutoff device that, at a predetermined distance, shut off the engine and sent the missile into free fall. The V-1's accuracy was terrible, often missing by several kilometers, but this very inaccuracy created enormous psychological fear, since no one knew where the next bomb would fall. Roughly ten thousand V-1s were fired at London and other cities, of which roughly 2,500 reached their targets and caused nearly six thousand deaths. After the war, this technology fell into American and Soviet hands and became the foundation for later generations of cruise missiles.

The Golden Generation: The Tomahawk, Flagship of the World's Cruise Missiles

It can be said without hesitation that the BGM-109 Tomahawk is the most famous and widely used cruise missile in history. The Tomahawk, brought into United States Navy service from the early 1980s, is the product of decades of experience in cruise-missile design. Notably, contrary to popular belief, the Tomahawk is not a new weapon; its first examples were designed in the mid-1970s, and its first operational launch came in 1983. But despite its age, through continuous upgrades, this missile has remained the weapon of choice for America's critical missions.

Technically, the Tomahawk is a subsonic missile, roughly 880 kilometers per hour, or Mach 0.8, with a range varying between 1,600 and 2,500 kilometers. Its length is roughly 5.56 meters, reaching 6.25 meters with the launch booster, its body diameter is 51.8 centimeters, and its launch weight is roughly 1,588 kilograms, of which roughly 450 kilograms is the powerful explosive warhead, or, in older versions, a nuclear warhead.

Newer Tomahawk versions, known as Block V, in service since 2021, come in two sub-versions: Block Va, an anti-ship version with moving-maritime-target capability, and Block Vb, a land-attack version with a new multi-purpose warhead. The active seeker radar in the anti-ship versions lets the Tomahawk find its target in the final moment and adjust even if the enemy vessel suddenly changes course.

But what sets the Tomahawk apart from all its predecessors is its combined guidance system. The Tomahawk uses a combination of an inertial navigation system, INS, to maintain the initial course, a GPS correction system for greater mid-course accuracy, a terrain contour matching system, TERCOM, which, using a digital map of the ground, compares its position against radar altimetry, and a digital scene-matching system, DSMAC, which, in the final phase, matches images of the target against stored images. The result is a stunning accuracy, with a circular error probable, CEP, of roughly ten meters, thirty feet. The TERCOM system, mid-course, using a digital map stored in the missile's computer, compares the missile's current altitude against the predicted altitude every few seconds and corrects course if a discrepancy exists. The DSMAC system, in the final phase, activates a small camera that matches images of the target area against reference images stored in memory so the missile strikes precisely the predetermined point.

Another key point in the Tomahawk's design is its capability for very-low-altitude flight. The Tomahawk can fly at an altitude of just fifty meters above the ground, or even ten meters above the sea, passing beneath the enemy's radar dome and appearing precisely over the target. This stealth capability has made the Tomahawk one of the most effective tools for attacking heavily defended targets. The modern Tomahawk Block V's range is roughly 1,600 kilometers, one thousand miles, and it can be launched from Arleigh Burke-class destroyers, Ticonderoga-class cruisers, Los Angeles- and Virginia-class submarines, and even mobile ground platforms. Its annual production rate is roughly two hundred to three hundred units, and the cost per unit is estimated at roughly two million dollars.

Other Notable Cruise Missiles of the World: Kalibr, Storm Shadow, SCALP, and Others

Russia's Kalibr, 3M-54, missile is a direct rival to the Tomahawk and gained fame in the war in Ukraine. The Kalibr family includes several versions: the 3M-54, an anti-ship version with a range of roughly three hundred kilometers and a supersonic terminal-phase capability, up to Mach 2.9, the 3M-14, a land-attack version with an estimated range of 1,500 to 2,500 kilometers, and the 91RE1, an anti-submarine version with a torpedo as its warhead. A key point in the 3M-54's design is its two-stage nature: in the cruise phase, it moves toward the target at subsonic speed, roughly Mach 0.8, and very low altitude, to stay hidden from radar, and at twenty kilometers from the target, its solid-fuel rocket motor activates and the missile accelerates to Mach 2.5 to 2.9, striking the target with violent maneuvers. Its warhead weighs four hundred to 450 kilograms and has high penetrating power against ship hulls and concrete bunkers.

Storm Shadow and its French version, SCALP, are long-range French and British cruise missiles. Its length is 5.1 meters, its weight 1,300 kilograms, and its warhead, 450 kilograms, is of the BROACH type, a two-stage warhead, a preliminary charge to punch through armor and then a main charge to detonate inside the target, specialized for penetrating hardened underground targets. The export version's range is 250 kilometers, and the French and British domestic version's range reaches 560 kilometers. This missile has been used in the wars in the Balkans, Iraq, Libya, and Syria, and has also been delivered to Ukraine. Storm Shadow uses combined INS, GPS, and image-matching DSMAC, guidance in the terminal phase and can fly at an altitude below fifty meters.

SCALP Naval, MdCN, is the naval version of this missile, fired from vertical launch silos on French ships, and with the addition of a launch booster, has a range similar to the air-launched version.

The BGM-109G Gryphon, ground-launched cruise missile, was a ground-based version of Tomahawk technology deployed in Europe and later destroyed under the INF Treaty. The CJ-10 missile, also known as the DH-10, is China's Tomahawk equivalent, with a range of roughly 1,500 to two thousand kilometers, in service with China's People's Liberation Army. China would use it to destroy strategic ground targets in the event of conflict with Taiwan or against American bases in Japan and Guam. The P-800 Oniks missile and its export version, Yakhont, are Russian supersonic anti-ship cruise missiles with a speed of Mach 2.5 to 2.6 and a range of roughly three hundred to five hundred kilometers, mounted on Gorshkov-class destroyers and the Pacific fleet. The BrahMos missile, a product of Russian-Indian cooperation built on Oniks technology, with a speed of Mach 2.8 and a range of 290 to 450 kilometers, is the fastest operational supersonic cruise missile in the world and is used by India's army, navy, and air force.

Iranian Cruise Missiles: Soumar, Hoveyzeh, Paveh, Abu Mahdi, and Kowsar

The Islamic Republic of Iran has, since the 1990s, seriously entered the field of designing and building cruise missiles and today is one of the few countries in the world capable of domestically producing a full range of these weapons. The evolutionary path of Iran's cruise missiles reflects a technological leap from reverse-engineering foreign examples to fully domestic design.

The Soumar family was the starting point of Iran's ground-based cruise-missile program. This missile was first unveiled in 2015 and, with a declared range of seven hundred kilometers, for the first time brought Iran's missile reach into the domain of long-range cruise missiles. Soumar, which closely resembles Russia's Kh-55 missile, examples of which were transferred to Iran in the 2000s, uses a small turbojet engine and, like the Tomahawk, can fly at very low altitude. Western analysts believe Soumar is not a simple copy but a reverse-engineered and improved version of the missiles obtained, and its true range may reach as much as two thousand kilometers. Soumar flies at an estimated speed of nine hundred to one thousand kilometers per hour and is equipped with combined guidance, INS and likely GPS. A small number of these missiles have been tested in armed-forces exercises.

Hoveyzeh, unveiled in 2018, is a more advanced version with a range beyond 1,350 kilometers and combined guidance. According to Iranian officials, Hoveyzeh can operate around the clock and in any weather condition and, owing to satellite positioning and a more advanced navigation system, has considerably greater accuracy. In appearance, Hoveyzeh has a more compact body than Soumar and appears to use a smaller, more fuel-efficient turbofan engine that enables greater range with the same fuel volume.

Paveh is without doubt the most advanced Iranian cruise missile unveiled to date. This missile's official range is stated as 1,650 kilometers, and it uses a more compact, more efficient engine than earlier generations. Paveh is small enough to be launched even from light military vehicles. This missile was presented to the media in 2022 and has since been tested repeatedly in armed-forces exercises. Paveh is equipped with folding wings, like the Tomahawk, that open after launch and increase lift surface. Its engine is a turbojet type, and its fuel is likely kerosene with special additives to increase efficiency.

Abu Mahdi is the name of another Iranian anti-ship and ground-based cruise missile. Named after General Abu Mahdi al-Muhandis, the Iraqi commander of the Popular Mobilization Forces who was killed alongside General Soleimani in a 2020 American airstrike, this missile has a range of roughly one thousand kilometers and can be mounted on fast boats and coastal platforms. Abu Mahdi is not a naval-developed version of the Mohajer-6, a combat drone, but a dedicated anti-ship cruise missile with a three-hundred to four-hundred-kilogram warhead designed to sink large ships. Its mid-course guidance is by INS and GPS, and its terminal phase by an active radar seeker, giving it fire-and-forget capability.

Kowsar is another Iranian cruise missile, designed specifically for the anti-ship role. Kowsar, produced in both air-launched and surface-launched versions, with a range of roughly two hundred kilometers and the capability to fly at three to five meters above the water's surface, makes detection and interception by enemy vessel radars very difficult in practice. This missile uses active radar guidance in the terminal phase and can target surface targets with high accuracy. Owing to its relatively small size, Kowsar is mounted on Sina- and Peykaan-class fast boats as well as larger Moudge-class vessels.

Alongside these missiles, Iran also has the Ghadir missile, a subsonic anti-ship cruise missile with a range of roughly two hundred to three hundred kilometers and the capability to be mounted on coastal platforms and vessels. Ghadir has been fired in numerous naval exercises and has struck moving maritime targets.

A notable point across all Iranian cruise missiles is the approach of full domestic production of their propulsion and guidance systems. While the first generation of these missiles, such as Soumar, was mainly based on reverse-engineering foreign examples, newer generations such as Paveh and Abu Mahdi are the product of fully domestic design and reflect the maturity of Iran's missile industry in this field. According to analysts, Iran's defense industry now has the capacity to produce more than one hundred cruise missiles of various types annually, and a program to develop new versions with a range of two thousand kilometers and higher accuracy is also underway.

Part Two: Ballistic Missiles, Swords That Fall from the Edge of the Atmosphere

Definition and Nature

Unlike cruise missiles, which fly continuously with the engine running, a ballistic missile, after its fuel is spent, continues its path in free fall along an elliptical arc. This is why it is called ballistic, a name drawn from the science of ballistics, the study of projectile motion.

A ballistic missile typically exits the atmosphere, reaches very high speeds in the vacuum of space, up to twenty-four thousand kilometers per hour, that is, Mach 20 or more, and then reenters the atmosphere at a steep angle to destroy the target at the lowest point of the arc. Physically, a ballistic missile follows Kepler's laws: its path, after engine cutoff, is an elliptical orbit whose focus is the center of the earth. The greater the missile's speed at apogee, the wider the orbit and the longer the missile's range.

Classification of Ballistic Missiles by Range

Ballistic missiles are divided into five categories by maximum operational range: short-range ballistic missiles, SRBM, range under one thousand kilometers, tactical battlefield projectiles, examples: the Scud, Iran's Fateh -110, Russia's Tochka-U; medium-range ballistic missiles, MRBM, range one thousand to three thousand kilometers, examples: Iran's Shahab-3, Sejil, Zolfaghar, Hejaz, Iran's new version; intermediate-range ballistic missiles, IRBM, range three thousand to 5,500 kilometers, a bridge between tactic and strategy, example: Sejil-2 and likely Khorramshahr-4, upgraded Iranian versions; intercontinental ballistic missiles, ICBM, range beyond 5,500 kilometers, often up to ten thousand to fifteen thousand kilometers, the primary pillar of nuclear deterrence; and submarine-launched ballistic missiles, SLBM, a subgroup of ICBMs launched from submarines.

The Physics of Ballistic Flight: Three Stages

The flight path of a ballistic missile is divided into three stages, each presenting unique challenges for interception and defense.

The first stage, boost phase: from the moment of launch to the end of main-engine burn, roughly three to five minutes for ICBMs. In this stage, the missile exits its silo or mobile launcher with high acceleration and passes through the atmosphere. The missile is highly vulnerable in this stage since it has not yet reached full speed and leaves a large thermal signature. Even so, this stage's duration is very short, and interception requires space-based systems, such as SBIRS warning satellites, that can detect the infrared radiation from the rocket engine's exhaust within seconds of launch.

The second stage, midcourse phase: after engine cutoff, the missile travels toward the target outside the atmosphere, above one hundred kilometers altitude. This is the longest stage, roughly twenty minutes for an ICBM, and is considered the golden window for interception. In this stage, the missile moves through the vacuum of space, and its path is calculable by the laws of physics, but decoys, aluminized balloons with a radar signature similar to the real warhead, complicate interception. Maneuverable reentry vehicles, MaRVs, capable of changing course, also challenge interceptor systems.

The third stage, terminal phase: when the warhead enters the atmosphere, roughly one hundred kilometers altitude, it heats to several thousand degrees Celsius owing to air friction. The warhead's speed in this stage drops to five to ten times the speed of sound, and only a very short time, seconds until impact, remains for interception. Defense systems such as Patriot or the S-300 can engage in this stage, but face the problem of an extraordinarily short reaction time.

Maneuverable warheads can execute violent maneuvers in this stage, making interception nearly impossible.

Intercontinental Ballistic Missiles: The Ceiling of Power

At the apex of the ballistic-missile pyramid stand intercontinental ballistic missiles, ICBMs. These giants, some up to thirty-five meters long and up to two hundred tons in weight, can deliver warheads weighing one to three tons to any point on the globe within half an hour, a range that constitutes the most important difference between a regional power and a global one.

America's LGM-30 Minuteman III is the world's oldest active ICBM, remaining in service since the 1970s through repeated upgrades. With more than four hundred units deployed in underground silos in Montana, North Dakota, and Wyoming, it forms the backbone of American nuclear deterrence. This three-stage, solid-fuel missile, a feature vital for ICBMs since it reduces preparation time from hours, liquid fuel, to minutes, is 18.2 meters long, 1.7 meters in diameter, and weighs 35.3 tons at launch. The Minuteman III has a range of roughly thirteen thousand kilometers, a speed of Mach 23, more than 28,000 kilometers per hour, and can carry a thermonuclear warhead with a yield of 335 to 475 kilotons, equivalent to twenty-two to thirty-two times the Hiroshima bomb. Its successor, the LGM-35A Sentinel, with more advanced capabilities and a cost of one hundred billion dollars for 650 units, is set to replace the Minuteman from 2029.

Russia, however, has gone a step further. The RS-28 Sarmat, or Satan II, is Russia's newest ICBM. With a launch weight beyond 208 tons, a length of 35.5 meters, and a diameter of three meters, this missile has a range of eighteen thousand kilometers and can carry up to ten tons of warheads, equivalent to ten to fifteen independent nuclear warheads, MIRVs. Sarmat is capable of carrying a heavy multi-megaton warhead or multiple warheads with a combined yield beyond fifty megatons. Sarmat's unique feature is its capability to fly unconventional trajectories, including over the South Pole, to evade American early-warning systems based in Alaska and Greenland. Its accuracy, CEP, is estimated at roughly five hundred to one thousand meters, but given the high yield of the nuclear warhead, this error is inconsequential. Its engine uses liquid fuel, which cannot be stored long-term in the silo, unlike solid fuel, but provides far greater thrust and is necessary for carrying heavy warheads.

China has also operationalized its new generation of ICBMs, known as the Dongfeng-41, DF-41. With an estimated range of fifteen thousand kilometers, a speed of Mach 25, the capacity to carry ten MIRV warheads with a combined weight of 2,500 kilograms, and the capability of launch from mobile road vehicles, TEL systems, this missile has brought China into the club of elite ICBM powers. Its length is estimated at roughly 16.5 to twenty-two meters and its weight at roughly eighty tons. Its fuel is solid, unlike many of China's older liquid-fueled ICBMs, which sharply reduces reaction time. The DF-41 has recently also been tested with maneuverable hypersonic glide vehicle, HGV, warheads. The Dongfeng-5, DF-5, is China's oldest ICBM, liquid-fueled with a range of twelve thousand to fifteen thousand kilometers, and the Dongfeng-31, DF-31AG, is a road-mobile, solid-fuel version with a range of roughly twelve thousand kilometers.

Iranian Ballistic Missiles: From the Shahab to the Fattah and Kheibar Shekan

Iran's ballistic-missile program is without doubt one of the most advanced and diverse programs among developing countries. Over the past four decades, Iran has not only domesticated short-range missile technology but has also joined the ranks of countries possessing medium-range ballistic missiles capable of carrying advanced warheads. What distinguishes Iran's missile program from many other countries is its reliance on solid propulsion in the new generation and precision-targeting capability with an error under fifty meters.

The First Generation: Shahab-1 and Shahab-2

The foundations of Iran's missile program were laid on the Soviet, and North Korean, Scud-B and Scud-C missiles. Shahab-1, derived from the Scud-B, with a range of roughly three hundred kilometers and a thousand-kilogram

warhead, was the first operational missile after the war. Shahab-2, with a range of roughly five hundred kilometers, is considered its improved version. Both remain in Iran's arsenal and were also used against Iraqi cities and Baathist forces during the Iran-Iraq War.

Shahab-3: A Historic Turning Point

Shahab-3, first unveiled in 2003, is a missile that permanently transformed Iran's deterrence landscape. After the American attack on Iraq in 2003, which posed a direct threat to Iran's national security, Iran focused on developing long-range missiles, and Shahab-3 was the fruit of this effort. This medium-range ballistic missile, with a range of 1,300 to 2,100 kilometers, depending on model and warhead configuration, and a weight of roughly sixteen tons, for the first time brought Israel and American bases in the Middle East within range of Iran's missile threat. Shahab-3 uses liquid fuel, which increases fueling and preparation time but offers high flexibility in adjusting range and warhead. Its length is roughly sixteen meters, its body diameter 1.3 meters, and its warhead weighs roughly 750 to 1,200 kilograms.

The Ghadr and Emad Family: Precision and Control

Ghadr and Emad are two upgraded ballistic missiles derived from Shahab-3, built with the goals of increased range, Ghadr, up to two thousand kilometers, and improved accuracy, Emad, as the first Iranian missile with terminal-phase guidance. Emad, unveiled in 2015, with a length of 15.5 meters, a weight of seventeen tons, and a range of 1,700 kilometers, was the first to feature a warhead maneuverable in the aerodynamic reentry phase, reducing its circular error probable, CEP, to roughly fifty meters, a dramatic reduction compared to earlier generations, which had an error of five hundred to three thousand meters.

The Bavar-373, a defensive missile, though this missile does not fall within the offensive ballistic category, should not be confused with the 373 defense system, which operates in the mid-tier defense layer.

Sejjil: A Revolutionary Solid Fuel

Sejjil was Iran's great leap toward advanced solid-fuel missile technology. Sejjil, first launched in 2008, is a two-stage missile with a range of two thousand to 2,500 kilometers and a body diameter of 1.2 to 1.4 meters. Sejjil's main advantage over Shahab-3 is its solid fuel: far shorter preparation time, long-term storage capability without needing to drain and refuel, and lower vulnerability to satellite detection, since the missile can sit in storage for years and be ready for launch within minutes of the firing order. Also, Sejjil's flight outside the atmosphere reaches a speed of roughly Mach 16, roughly twenty thousand kilometers per hour, making interception difficult for air-defense systems.

Zolfaghar, Fateh-313, and Kheibar Shekan

Zolfaghar is a single-stage, solid-fuel tactical ballistic missile derived from the Fateh-110 family but with significant improvements. This missile has a range of seven hundred kilometers and a warhead weighing roughly 580 kilograms. Zolfaghar is compact enough to be mounted on mobile launcher vehicles with two launchers, and its preparation time is only a few minutes, owing to its solid fuel. This missile played a central role in Iran's 2024 attack on Israel, Operation True Promise. Zolfaghar uses combined INS and GPS, or a local satellite receiver, guidance, and its CEP is estimated at roughly fifty to one hundred meters.

Fateh-313 is a successor to the Fateh-110 with a range of roughly five hundred kilometers, whose weight has been sharply reduced and accuracy considerably increased through aerodynamic optimization and the use of composite materials. Fateh-313, with a single-stage solid-fuel engine and a warhead of three hundred to 450 kilograms, is one of the main missiles of the IRGC Aerospace Force for tactical strikes on targets deep within enemy territory.

Kheibar Shekan, unveiled in 2022, is one of Iran's newest ballistic missiles. This solid-fuel missile, with a range of 1,450 kilometers, uses a new generation of composite propellants with higher energy density, allowing a reduction in missile size while preserving range. Among Kheibar Shekan's notable features are terminal-phase maneuvering capability, with four small control fins on the warhead, and very high targeting accuracy, CEP under thirty meters.

according to Iranian officials' claims. Kheibar Shekan has successfully executed precision strikes on point targets, such as simulated S-300 defenses, in IRGC exercises.

Newer Missiles: Haj Qasem and Rezvan

The Haj Qasem missile, unveiled in 2020 after the assassination of General Soleimani that same year, is a medium-range ballistic missile with a range of 1,400 kilometers, some sources say up to 1,800 kilometers, designed to target American bases in the region. This missile can carry a warhead of five hundred to one thousand kilograms. The Rezvan missile is a short-range, liquid-fuel ballistic missile with a range of roughly three hundred to five hundred kilometers.

An important point regarding Iran's missile program is its non-development of intercontinental ballistic missiles, ICBMs, with a range beyond 5,500 kilometers, a decision Iran has repeatedly emphasized as part of its defense doctrine; it says it does not seek the capability to strike Europe or America but is focused on regional deterrence. Even so, many Western analysts believe Iran's technical distance to an ICBM is short, and should its doctrine change, Iran could acquire such a capability within a few years.

Part Three: Hypersonic Missiles, a Double-Edged Sword of Destiny

Definition and Nature

Hypersonic missiles are weapons capable of flying at speeds beyond Mach 5, five times the speed of sound, roughly 6,100 kilometers per hour, but, unlike ordinary ballistic missiles, have a flight path that is fully maneuverable within the atmosphere and is not easily predictable. The combination of these two features, dazzling speed and maneuverability, together creates a game-changing weapon capable of penetrating any existing defense system. This is because current defense systems are designed either to intercept ballistic targets with a predictable path, such as Patriot and the S-300 in the terminal layer, or subsonic maneuverable targets, such as cruise missiles, but at low speed. A hypersonic weapon has neither a predictable path, since it flies within the atmosphere and constantly changes direction, nor low speed.

Hypersonic missiles fall into two main categories. First, the hypersonic glide vehicle, HGV: this weapon is first carried to the edge of space, eighty to one hundred kilometers altitude, by an ordinary ballistic missile, then the glide warhead separates from the missile body and descends through the atmosphere at a speed beyond Mach 5. The distinguishing feature of an HGV from an ordinary ballistic warhead is its maneuverability. While an ordinary ballistic warhead, once separated, can no longer change course and only falls freely, an HGV is equipped with aerodynamic control surfaces, fins and tail, and can follow complex, unpredictable paths to reach the target.

Second, the hypersonic cruise missile, HCM: this weapon travels its entire flight path with the engine running, at a speed beyond Mach 5. Its propulsion is typically a scramjet, supersonic combustion ramjet, an engine that draws atmospheric air into itself without a compressor, unlike ordinary jet engines, at supersonic speed, mixes it with fuel, and ignites it. The main challenge of the scramjet is igniting fuel within a supersonic airflow, similar to lighting a match in a storm. This challenge has, after decades of research and development, finally been solved to some degree by Russia, China, and the United States.

Russia's Hypersonic Missiles: Zircon, Kh-47M2, and Avangard

Russia is without doubt the world leader in hypersonic weapons, and Vladimir Putin has repeatedly referred to these weapons as next-generation weapons. After the annexation of Crimea and the imposition of Western sanctions on Russia in 2014, the Kremlin accelerated its hypersonic programs with an enormous budget, and today Russia is one of the few countries with several operational hypersonic systems in its arsenal.

Zircon, 3M22 Zircon, is the heart of Russia's hypersonic program. Zircon is a hypersonic anti-ship and land-attack cruise missile launched from ships and submarines. Its speed is officially stated as Mach 8 to 9, eight to nine times the speed of sound, roughly ten thousand kilometers per hour, and its range is stated as beyond one thousand kilometers. Its engine is a dual-mode rocket-ramjet: first a solid-fuel rocket motor brings it to sufficient speed, roughly Mach 2, then the scramjet engine activates and accelerates the missile to Mach 9. Zircon is equipped with combined INS,

satellite, and active radar seeker guidance in the terminal phase. In the final flight phase, Zircon is capable of violent aerodynamic maneuvers, using control fins, that make its path entirely unpredictable for defense systems such as Aegis and Patriot. In February 2024, it was reported that Zircon was likely used for the first time in an attack on Ukraine. Zircon is mounted on Admiral Gorshkov-class ships and Yasen-M-class submarines, and by 2026 roughly two hundred units have been produced.

The Kh-47M2 Kinzhal, dagger, is an air-launched ballistic missile with a hypersonic glide warhead, a type of simple HGV. Kinzhal, carried and launched by the MiG-31K bomber, flies at a speed of roughly Mach 2.8, with afterburner, and releases the missile at high altitude, fifteen to twenty kilometers. The missile then, with its own solid-fuel rocket motor, climbs to an altitude of eighty kilometers and reaches a speed of Mach 10 to 12, 12,000 kilometers per hour. Its warhead, 480 to five hundred kilograms, consisting of conventional explosives or a nuclear warhead, can target both fixed and moving targets, such as ships. Maneuvering capability in the terminal phase, using small fins, allows Kinzhal to pass through defense systems. Kinzhal has been used extensively in the war in Ukraine, more than forty-four times in 2022 to 2024, and has destroyed hardened underground targets. The American Patriot system has, in some cases, early 2023, managed to intercept older Kinzhals, but more updated versions with terminal maneuvers have made interception more difficult for any system.

Avangard is an advanced hypersonic glide vehicle, HGV, carried by Russia's heavy intercontinental ballistic missiles, such as the UR-100NUTTH, R-36M2, and RS-28 Sarmat. Its dimensions are roughly 5.4 meters in length, and its weight is estimated at roughly two thousand kilograms. After separating from the launch platform, Avangard enters the upper layers of the atmosphere and moves toward the target at a speed exceeding Mach 20 to 27, 25,000 to 34,000 kilometers per hour, the fastest operational weapon in the world, while capable of violent maneuvers and sudden changes of direction along the entire path. Its heat shield is made of carbon-carbon composite material with a melting point beyond three thousand degrees Celsius to withstand the heat generated by atmospheric friction. According to Russian officials, Avangard is effectively unable to be intercepted by any existing defense system and entered operational service in late 2019.

China's Hypersonic Missiles: DF-17, DF-ZF, and the New Generation

China too has joined the hypersonic club with impressive speed and, in some areas, has surpassed Russia and the United States. China's programs are mainly led by the Academy of Rocket Science and the Beijing Institute of Aerospace Research, and some Western analysts believe China has more than two hundred supersonic wind tunnels, the largest research infrastructure in this field.

The Dongfeng-17, DF-17, is the world's first medium-range ballistic missile designed specifically to carry the DF-ZF hypersonic glide warhead. The DF-17, first unveiled in 2019 at Beijing's military parade for the seventieth anniversary of the founding of the People's Republic of China, with a range of 1,800 to 2,500 kilometers, releases its warhead after reaching the edge of the atmosphere. Its engine is solid-fuel and two-stage. The DF-ZF, a glide vehicle with a waverider body, a special design that traps the shock wave from supersonic flight beneath the body to generate additional lift, maneuvers at Mach 5 to 10 just above the atmospheric layer and follows a fully non-ballistic, unpredictable path. Evidence suggests China had operationalized more than two hundred DF-17 units by 2025, each mounted on a mobile TEL launch vehicle, and presents it as a carrier-killer and a piercer of Taiwan's defense system.

Beyond the DF-17, China has developed other hypersonic missiles, including the Changjian-100, CJ-100, DF-100, a supersonic-hypersonic cruise missile, speed four to six Mach, with a range of two thousand to three thousand kilometers, and the YJ-21, a hypersonic anti-ship missile. Numerous tests of the Xingkong-2, Starry Sky-2, glide warhead have also been reported in Chinese media. The DF-17's accuracy in field tests has been reported as a few meters and can strike a target with an error under ten meters.

America's Hypersonics: A Struggle to Catch Up

Although the United States is the spiritual father of hypersonic technology, NASA's research foundation in the 1960s with the X-15 project, which reached Mach 6.7, it has fallen behind its rivals in the operational development of these weapons. The reasons for this lag include prioritizing the counter-terrorism war in the 2000s and 2010s, which did not require hypersonics, cuts to research funding after the end of the Cold War, and excessive reliance on traditional nuclear deterrence. Even so, several major programs have been defined to make up this lag.

The AGM-183A ARRW, a rocket-ramjet missile, is an air-launched ballistic missile with a glide warhead, HGV, developed by the United States Air Force. Despite delays and several failed tests in 2021 to 2023, it finally achieved its first successful launch in 2024. Its target speed is Mach 6 to 8, 7,400 to 9,800 kilometers per hour, and its range is roughly 1,600 kilometers. It is designed for launch from B-52H and B-1B Lancer bombers.

The CPS, Conventional Prompt Strike, is a hypersonic glide warhead, HGV, launched from ships, Arleigh Burke-class destroyers and Zumwalt-class ships, and ground platforms. Its speed is roughly Mach 7 to 8 and its range 2,700 to 3,200 kilometers. It is being developed by the United States Navy and Army and is expected to enter service from 2027.

Long Shot is a DARPA program to build a hypersonic cruise missile with a scramjet engine.

OpFires, Operational Fires, is an army program to build a ground-based hypersonic missile with a range of roughly one thousand to 1,800 kilometers.

The absence of an operational hypersonic missile in America's arsenal through the mid-2020s is regarded as a serious strategic vulnerability, which the Pentagon has sought to remedy with a budget beyond five billion dollars in fiscal years 2024 to 2025. America's first hypersonic systems are expected to enter service in 2027 to 2028.

Other Hypersonic Powers: North Korea and Beyond

North Korea is one of the newest and most surprising members of the hypersonic club. In 2021, North Korea tested its first hypersonic missile, named Hwasong-8. This missile is equipped with a glide warhead, HGV, and Western analysts believe its technology likely originated in Russia or China. In 2022, North Korea tested the Hwasong-16B missile, with hypersonic capability and a range of roughly one thousand to 1,500 kilometers. The Mars-8, displayed at Pyongyang's 2023 military parade, also uses a type of HGV.

India is also developing the BrahMos-II hypersonic missile, with a target speed of Mach 7 to 8 and a scramjet engine, set to become operational by 2028 to 2029.

Australia and Britain also have joint research projects with the United States in scramjet and HGV technology.

Iran's Hypersonic Missile: Fattah

On November 9, 2022, the Islamic Republic of Iran formally announced its entry into the club of countries possessing hypersonic weapons. This weapon, named Fattah, is a ballistic missile with a hypersonic glide warhead, HGV, designed and developed by the IRGC Aerospace Force. Iran is the sixth country, after Russia, China, the United States, North Korea, and likely South Korea, to achieve this technology.

According to Iranian officials, Fattah is known for the following features: a speed of up to Mach 14 to 15, 21,420 kilometers per hour, fourteen to fifteen times the speed of sound; a range between 1,400 and two thousand kilometers depending on configuration; a maneuverable, movable warhead, HGV, equipped with a small engine and four control fins capable of changing course in the final flight phase and passing through defense systems such as Iron Dome, Arrow, and Patriot; a solid, composite propellant with high energy density and a movable carbon nozzle, thrust vector control, TVC, providing extraordinary maneuverability across all flight phases, Fattah's engine uses two separate stages, the first for initial acceleration, the second to bring the warhead to hypersonic speed; and an estimated length of twelve meters and a weight of roughly seven to eight tons.

In 2023, an improved version of this weapon named Fattah-2 was unveiled at Iranian military exhibitions. Fattah-2, with changes in aerodynamics, a nose with a sloped body to reduce drag, and thermal improvements, the use of super-heat-resistant materials such as heat-resistant ceramics at the warhead tip that withstand temperatures beyond two thousand degrees Celsius, performs better at very high speeds. According to analysts, Fattah is classified among the most formidable of Iran's ballistic missiles.

Although at the time of this chapter's writing no independent confirmation of Fattah's operational tests is available, its official unveiling and the claims of senior officials, including General Hajizadeh, commander of the IRGC Aerospace Force, along with some media reports of its possible use, though unconfirmed, in the 2024 attack on Israel, indicate

Iran's serious intent to enter the age of hypersonic weapons. Israeli analysts warned after the True Promise attack in April 2024 that if Fattah is truly what it claims to be, the future of Israeli air defense will face an unprecedented challenge.

Part Four: Anti-Tank Rockets and Missiles, Armored Hunters of the Battlefield

The Emergence of the First Anti-Tank Missiles

The story of anti-tank missiles begins in the closing years of the Second World War, when Nazi Germany, and subsequently the great powers, realized that the armor of advanced tanks, such as the Soviet T-34, with forty-five-millimeter sloped armor, and the German Tiger, with one-hundred-millimeter armor, had grown so thick that ordinary anti-tank gun shells, thirty-seven to fifty-millimeter caliber, were unable to penetrate them. The solution was a projectile that could guide itself toward the tank, not in the straight line of a cannon, which requires direct line of sight and is blocked by terrain obstacles, but with a small engine and a rudimentary guidance system.

The Germans developed the world's first operational anti-tank missile, the X-7 Rotkäppchen, Little Red Riding Hood, in 1944. This small missile used wire guidance, the simplest form of anti-tank guidance, but owing to Allied bombing of the factories, arrived on the battlefield too late to play a decisive role. After the war, the Soviet Union, with the AT-1 Snapper series, operational in the 1950s, France, with the ENTAC missile in 1957, and the United States, with the SS.10 missile in 1955, began an extensive competition in developing anti-tank missiles. The Soviet Union chose the path of simplicity and mass production, the AT-3 Sagger missiles, which destroyed hundreds of Israeli tanks in the 1973 Arab-Israeli war, while the West focused on high accuracy and advanced guidance.

Guidance Technology: From Wire to Thermal Laser Seeker

Modern anti-tank missiles have passed through four main generations of guidance technology.

First generation, manual command to line of sight, MCLOS: the user, with a small joystick, manually guides the missile toward the target after launch. The user must keep the target in the sight and simultaneously detect the missile's deviation from the line of sight and send correction commands. This was effective only for very skilled users, usually after hundreds of hours of practice. Examples: the Soviet Malyutka, known as the AT-3 Sagger, and Iran's Raad, early version.

Second generation, semi-automatic command to line of sight, SACLOS: the user need only keep the target at the center of the sight, like an ordinary rifle. An automatic system, usually a tracking camera at the rear of the missile, calculates the deviation of the missile's path from the line of sight and sends correction commands to the missile via a wire, or a short-range radio link. This technology, first operational in the American TOW missile in the late 1960s, dramatically increased accuracy and sharply reduced the skill required of the shooter.

Third generation, fire-and-forget: after launch, the missile automatically tracks the target using an imaging infrared, IIR, receiver or thermal hot-spot detection, and no longer requires user intervention until impact. After locking onto the target, using the thermal camera within the command unit, and firing, the user can immediately leave the position or move to the next target. Examples: the American Javelin, operational since 1996, the Israeli Spike, and the Chinese HJ-12, all of which use this technology.

Fourth generation, combined guidance with violent maneuvering capability and in-flight update, lock-on after launch, LOAL: the newest generation of anti-tank missiles can be aimed at an approximate target area, for example behind a hill, where the shooter has no direct line of sight to the target, and after reaching that area, automatically search for and lock onto the target. There is also the capability of course updates via fiber optics or an advanced data link, so the user can change targets mid-flight or stay aware of the scene, live images from the missile's camera. Examples: the Israeli Spike-LR and some newer Javelin versions.

Important Anti-Tank Missiles of the World

The BGM-71 TOW, Tube-launched, Optically tracked, Wire-guided, in service with the United States and dozens of other countries, including Iran, since 1970, is one of the most widely produced anti-tank missiles in the world, with more than 690,000 units built. The missile's length is 1.17 to 1.45 meters, its diameter 150 millimeters, its warhead weight roughly 6.2 kilograms, its penetrating power beyond six hundred millimeters of steel armor, and in newer models up to one thousand millimeters using tandem warheads, its standard effective range 3,750 meters, new version up to 4,500 meters, and its speed roughly 299 meters per second, roughly Mach 0.9. TOW uses semi-automatic, SACLOS, guidance with commands sent via a thin, two-strand wire, the wire's length equals the missile's range, and is mounted on armored vehicles, helicopters, the TOW-2/2A/2B model for the Cobra and Apache, and tripod platforms. The TOW missile, owing to its wire guidance, is immune to any electronic jamming, but the wire can be severed on contact with a tree or obstacle.

The FGM-148 Javelin, known as the tank killer, is a third-generation American missile with imaging-infrared fire-and-forget guidance that regained global fame owing to its dazzling performance in the war in Ukraine, where it destroyed hundreds of modern Russian tanks. After locking onto the target, carried out through the thermal sight, CLU, Command Launch Unit, capable of detecting a tank's body heat from several kilometers, and firing, the user launches the missile toward the target and can immediately leave the position. Javelin is designed to penetrate from above, top attack, since a tank's weakest armor point is the turret top, usually fifteen to thirty millimeters. Its penetrating power reaches eight hundred millimeters of armor, and its range reaches 4,750 meters in the FGM-148F version, the newest version with a multi-purpose warhead, MPWH. The portable system's weight is 22.3 kilograms, distributed between two people, the shooter and the ammunition bearer. Javelin, being infrared-based, also functions in total darkness and amid smoke and fog, unlike laser missiles, which are sensitive to smoke. During the war in Ukraine, 2022 to present, the United States and its allies have sent more than ten thousand Javelin missiles to Ukraine, which played an important role in halting Russia's armored advance in the war's first weeks.

Spike, made by Israel, is the most diverse family of third- and fourth-generation anti-tank missiles. Its various models include the Spike-SR, short-range, two to four kilometers, weight ten kilograms, the Spike-MR, range 2.5 to five kilometers, the Spike-LR, range up to eight kilometers, the Spike-ER, range up to ten kilometers, helicopter-launched, and the Spike-NLOS, range up to thirty to forty kilometers, beyond line of sight. Spike uses combined fiber-optic guidance, the shooter can see the missile's camera images on a display during flight and change targets, and fire-and-forget capability, with an infrared receiver, and can be fired from individual, vehicle, naval, and airborne platforms. Spike is in service with many NATO countries as well as some Arab countries, and Israel has used it against Hamas ground targets in Gaza.

The 9M133 Kornet, made by Russia, is a second-/third-generation missile with semi-automatic laser guidance, laser SACLOS, which, owing to its very high penetrating power, up to 1,200 to 1,300 millimeters of steel armor using a tandem-charge warhead that passes through explosive reactive armor, ERA, which deflects the round with its own small explosion, the tandem warhead neutralizes the reactive armor with its first charge and penetrates the main armor with its second, and its effective range of 5,500 to eight thousand meters, the Kornet-EM model up to ten thousand meters, has among the highest destruction rates of any anti-tank missile in the world. Kornet can also attack helicopters, if within range and line of sight, and hardened concrete bunkers. The Kornet missile has been used extensively in the wars in Iraq, Syria, Yemen, and Ukraine, and has destroyed American Abrams tanks, in Iraq, and German Leopard 2 tanks, in Ukraine. Reverse engineering of this missile in Iran has resulted in the Dehlavieh.

The NLAW, Next-generation Light Anti-tank Weapon, made by Sweden and Britain, is a light, 12.5-kilogram, single-use missile with a range of twenty to eight hundred meters, mostly for close ranges, using Predicted Line of Sight guidance, a type of semi-automatic system in which the user tracks a moving target for a few seconds and the missile's computer calculates the target's speed and path and predicts the point of impact. This technology sits between MCLOS, first generation, and SACLOS, second generation. NLAW is optimized for top attacks at short range and became known in the war in Ukraine as the killer of Russian tanks in urban warfare and close range. Roughly fourteen thousand of these missiles have been produced in Britain, and thousands have been sent to Ukraine.

Brimstone, made by Britain, ground and air versions, is an extremely fast, supersonic, roughly Mach 1.3, anti-tank missile weighing fifty kilograms, 180 millimeters in diameter, 1.8 meters long, with a 6.3-kilogram tandem warhead, and a range of twelve kilometers, ground version, to sixty kilometers, air-launched from fixed-wing aircraft. Its guidance is millimetric-wave radar, which works in any weather condition, rain, smoke, fog. Brimstone's unique feature is swarm-attack capability: an aircraft can fire six to twelve Brimstones simultaneously, and each missile

automatically finds and destroys a different target among a group of armored vehicles. Brimstone has been sent to Ukraine by Britain and is fired from BAE Systems drones and ground platforms.

The HJ-12, Hongjian-12, Red Arrow 12, made by China, is a third-generation anti-tank missile with imaging-infrared, fire-and-forget, guidance similar to the American Javelin. The total system weight is twenty-two kilograms, fifteen kilograms missile plus seven kilograms sighting unit, the missile diameter 13.5 to fourteen centimeters, the tandem warhead with penetrating power up to 1,100 millimeters of steel armor passing through ERA, range four thousand meters by day and two thousand meters by night, and soft-launch capability from enclosed spaces, a slow exit from the tube before the main engine ignites, allowing a soldier to fire from within a building without exposure to toxic exhaust gases. The HJ-12 is produced for China's infantry forces in the mountainous regions of the India-Pakistan border as well as for export to African and Middle Eastern countries.

Iranian Anti-Tank Missiles: From the Raad to the Dehlaviyeh, Almas, and Toophan

Iran's defense industry has, over four decades, developed and produced a full range of anti-tank missiles and anti-armor rockets, some of which have now reached the third and fourth generation. These missiles have been extensively supplied to Lebanon's Hezbollah, the resistance forces in Iraq and Syria, and Iran's own army.

The Raad family, developed based on reverse engineering of the Soviet Malyutka, 9K11 Malyutka, AT-3 Sagger, missile, which was successful in the 1973 Arab-Israeli war and destroyed Israeli tanks, during the Iran-Iraq War, using captured examples, is Iran's oldest anti-tank missile family. Its range is roughly three to five kilometers, and its penetrating power reaches five hundred to six hundred millimeters of armor with a simple HEAT warhead. Raad uses manual, MCLOS, or simple semi-automatic, wired SACLOS, guidance and requires high shooter skill. A more modern version, Raad-500, with improved guidance and warhead, using a tandem warhead, has been introduced and is still seen in some IRGC and army units.

Toophan is Iran's family of TOW missiles, developed through reverse engineering of examples obtained of the BGM-71 TOW missile, likely from Iraq or Lebanon. Toophan, in various versions, Toophan-1, -2, -5, and -6, with a range of roughly 3,500 to four thousand meters and improved penetrating power, up to eight hundred millimeters in newer models, is offered with wired SACLOS guidance. Toophan can be fired from tripod platforms, armored vehicles, Toophan is mounted on Iranian BMP-2 vehicles, and Cobra helicopters, air-launched version. Iran claims the Toophan-6 warhead can penetrate the reactive armor, ERA, of Israeli Merkava tanks.

Dehlaviyeh is Iran's masterpiece of reverse engineering of the Russian Kornet, 9M133 Kornet, missile, one of the world's most powerful anti-tank missiles. Dehlaviyeh is an unlicensed copy of the Kornet, with the same appearance, guidance, laser SACLOS, and stated performance. It uses a tandem-charge warhead capable of penetrating reactive armor, ERA. Its precise technical specifications are: missile weight 22.7 kilograms, a two-stage warhead weighing 6.8 kilograms, penetrating power beyond 1,200 millimeters of steel armor, passing through any known ERA type, a secondary warhead of pure copper with a diameter of one hundred millimeters. Its range is between 3,500 meters, at night using night vision, and eight thousand meters, for updated newer versions, and, according to Russian sources, up to ten kilometers. Its guidance is semi-automatic laser, SACLOS, with an optional thermal seeker, ensuring high accuracy by day and in good weather conditions, fog and heavy smoke reduce laser effectiveness. Dehlaviyeh was first used in 2006 by Lebanon's Hezbollah against Israeli Merkava tanks and proved considerably more powerful than the Raad and Toophan. Iran today produces the Dehlaviyeh in ground, tripod, M113 vehicle, naval, fast boats, and airborne, Cobra and Bell 214 helicopters, versions with a range up to eight kilometers.

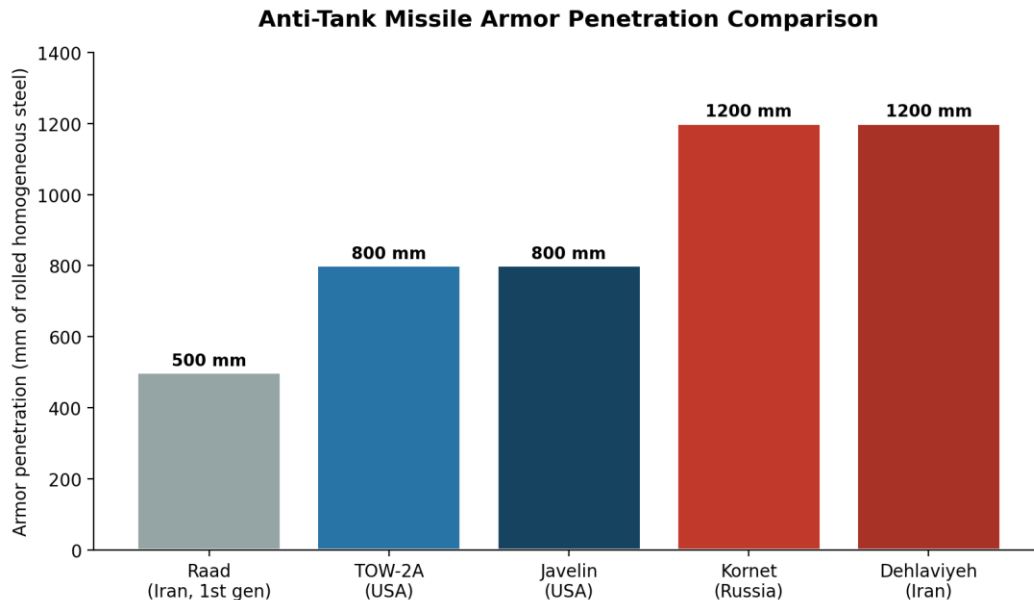


Chart: Approximate armor-penetration capability of selected anti-tank guided missiles (author's diagram, illustrative estimates).

Almas is Iran's newest and most advanced anti-tank missile, of the third, fire-and-forget, generation, developed based on reverse engineering of the Israeli Spike missile, examples of which likely reached Iran via Lebanon or Syria. Almas, unveiled in 2024, with a range of roughly eight kilometers, Almas-1 version, and eleven kilometers, Almas-2 version, under development, has fire-and-forget capability, target lock before launch with a thermal camera, lock-on-after-launch, LOAL, capability, meaning the user first fires the missile toward an area and, after the missile reaches that area, the imaging seeker warhead itself finds the target, as well as the capability to update and change targets mid-flight via fiber optics, the shooter sees live images from the missile's camera on a display. These two features, LOAL and fiber optics, have made Almas an unrivaled weapon for asymmetric warfare and hunting advanced tanks such as the Merkava in mountainous terrain, where there is no direct line of sight. Almas is offered in airborne, mounted on Mohajer-6 and Kaman-12 drones, and ground, shoulder-launched and vehicle-mounted, versions, and Iran's Ministry of Defense has begun its mass production.

Saeqeh and Esfand, an RPG-29 type, are two other examples of short-range, up to three to four kilometers, shoulder-launched Iranian anti-armor rockets, falling into the category of rocket-propelled grenades, RPGs, with tandem-charge warheads. These light rockets, roughly ten to twelve kilograms, are designed mainly for infantry units and special forces and require no external guidance unit. Saeqeh is an RPG-7 type with a tandem warhead, penetration 750 millimeters, and Esfand is a copy of the famous Russian RPG-29, with penetration of nine hundred millimeters.

Tosan is an anti-armor missile with a very high speed, roughly one thousand meters per second, roughly Mach 3, and a range up to four kilometers, using a powerful two-stage solid-fuel propellant, the first stage only for exiting the tube, the second for acceleration. Tosan is mounted mainly on IRGC Navy fast boats and is designed for hunting enemy fast boats and light armored vessels. Owing to its supersonic speed, which sharply reduces the reaction time of enemy vessels' defense systems, and its close-range firing, it is effectively unable to be intercepted. Tosan is also mounted in an airborne version on Cobra helicopters.

Comparative Analysis and Future Outlook: Where the Four Branches Converge

Having surveyed each of the four missile categories in detail, we now turn to comparative analysis and a look at the future. What all of them share in the twenty-first century is the blurring of the line between defense and offense and the increasing speed of operations.

Technological Convergence and Defensive Challenges

The line between cruise and ballistic missiles is fading. The emergence of supersonic cruise missiles, such as BrahMos, and short-range ballistic missiles equipped with terminal-phase maneuvering systems, such as some Iranian Fattah missiles, means one can no longer confidently say a cruise missile is necessarily slow or that a ballistic missile has a predictable path. This technological convergence has sharply complicated the air-defense equation. A defense system meant to guard against all these threats must be capable of simultaneously intercepting maneuverable subsonic targets, cruise missiles, supersonic targets with a parabolic path, classic ballistic, and maneuverable hypersonic targets, HGV, a capability no existing defense system, from Patriot and the S-400 to THAAD and Iron Dome, can accomplish alone. For this reason, the defense structure of advanced countries is moving toward multi-layered defense: an outer layer for ICBMs and HGVs, with space-based interceptors, a middle layer for MRBMs, IRBMs, and some long-range cruise missiles, with systems such as THAAD, the S-400, and Arrow-3, and an inner layer for short-range missiles, rockets, and drones, with systems such as Patriot, the S-300, Iron Dome, and laser systems.

The Rise of New Powers: Self-Sufficiency Versus Dependency

Unlike the Cold War era, when only superpowers had the ability to produce advanced missiles, today countries such as Iran, North Korea, South Korea, India, Israel, and Pakistan have achieved notable self-sufficiency in one or more of the four main missile domains, cruise, ballistic, hypersonic, anti-tank. Iran is not only self-sufficient in short- and medium-range ballistic missiles but has also made notable progress in cruise missiles, the Soumar and Paveh families, anti-tank missiles, Almas and Dehlaviyeh, and, recently, hypersonics, Fattah. North Korea has transformed from a poor, sanctioned country into one of the possessors of hypersonic warheads and intercontinental and submarine-launched, Pukguksong, ballistic missiles.

The Future: Intelligence and Swarm Warfare

The next generation of anti-tank and cruise missiles will be equipped with artificial intelligence and machine learning. A smart cruise missile could, during flight, prioritize targets, for example distinguishing a commander's vehicle from within a convoy, bypass enemy defensive points, using a three-dimensional map of the area stored in memory, and, if it encounters jamming or deception, activate a passive guidance mode, such as image matching. Smart missile swarms are also emerging: dozens of low-cost cruise missiles communicate with one another and, by dividing tasks, saturate the enemy's defenses, while one expensive missile strikes the main target.

Final Summary: Four Branches of One Tree of Power

In this comprehensive chapter, we have examined in detail the four main branches of the world's sturdy tree of missile technology. Each branch has its own philosophy, and each, in turn, has redefined a form of the balance of power in the world.

Cruise missiles, with their agile, creeping flight held close to land and sea, are the weapon of choice for surgical, precise, surprise strikes on deep enemy targets. They catch the enemy off guard and pass beneath the roof of his defense. Iran, with the Soumar, Hoveyzeh, and especially Paveh generations, has reached an acceptable peak in this art. The cost per launch of a cruise missile, at least one to two million dollars, compared to a fighter aircraft, more than ten million dollars in operational cost per mission, is very cost-effective and is one of the main reasons for this weapon's spread among countries with limited defense budgets.

Ballistic missiles, with their long, thunderous arc at the edge of space, are considered a strategic-deterrence weapon. They are designed not for the precision of a surgical strike, but for widespread, unstoppable destruction. The existence of even a single ballistic missile with a nuclear warhead can change the entire strategic equation of a region. Iran, with the development of the Shahab-3, Ghadr, Sejil, Zolfaghar, and Kheibar Shekan generations, has become an influential country among those possessing IRBM and SRBM missiles, and Iran's ballistic-missile arsenal is now the largest and most diverse in the Middle East.

Hypersonic missiles, the bride of twenty-first-century missile technology, have broken the barriers of speed and maneuver and can evade any existing defense system. As of mid-2024, only five countries, Russia, Kinzhal, Zircon, Avangard, China, DF-17, DF-ZF, the United States, under development, North Korea, Hwasong-8, and Iran, Fattah, belong to this very exclusive club. With the unveiling of the Fattah missile, Iran officially announced it has joined this

club. Although complete operational information is not yet available, this entry alone constitutes a strategic shift in the balance of power in the Middle East.

Anti-tank missiles and rockets, though they appear the smallest member of this family in range and apparent scale, sometimes play the most vital role on the real battlefield. In the war in Ukraine, missiles such as Javelin and NLAW inflicted heavy casualties on the Russian army's thousands of tanks and armored vehicles. A modern army without proper infantry cover and electronic warfare is defenseless against a wave of third- and fourth-generation anti-tank missiles. Iran too, with the Raad, Toophan, Dehlaviyeh, and Almas families, has achieved full self-sufficiency in this field, and Almas, as a third-generation missile with fire-and-forget and lock-after-launch capability, represents a major technical leap.

In the end, what is common across all these branches is the path Iran has traveled from the beginning of the imposed war, with weak tanks and rudimentary Scud missiles that had a range of only three hundred kilometers and an error sometimes up to three kilometers, to today, with two-thousand-kilometer cruise missiles, solid-fuel ballistic missiles with a CEP of fifty meters, third-generation Almas anti-tank missiles, and entry into the hypersonic age with Fattah. This path shows that in today's complex world, missile capability is one of the central pillars of any country's defense doctrine and deterrence, and Iran, through the continuous, unceasing effort of its scientists, has become one of the influential actors in this arena on the global stage.

The future, however, holds new challenges as well: the emergence of hypersonic missiles beyond Mach 20, which are effectively unable to be intercepted, Russia's Avangard has reached Mach 27, sea-floor-launched ballistic missiles, and smart anti-tank munitions that guide themselves toward a tank using the sound of its engine. In such an environment, the missile race will continue not only among superpowers but among all regional countries, and will determine the global balance of power for decades to come.

Special Feature

Missile Defense and Air Defense Systems of the World

Modern air defense is divided into three main layers: long range, beyond one hundred kilometers, for countering bombers and long-range ballistic missiles, medium range, thirty to one hundred kilometers, for intercepting fighters and cruise missiles, and short range, under thirty kilometers, for point defense of sensitive installations. Among these, some systems are specifically designed to intercept ballistic missiles in the upper layers of the atmosphere.

The Patriot Family, MIM-104 Patriot: Flagship of Western Defense

The Patriot system, in service with the American military and its allies since the early 1980s, is a long-range, all-weather surface-to-air missile system designed to counter aircraft, cruise missiles, and tactical ballistic missiles. Its radar is a passive phased-array AN/MPQ-53, with a range of roughly 170 kilometers and C-band frequency. Maximum interception range in early versions was roughly eighty kilometers, increased in newer versions to beyond one hundred kilometers, and it can destroy targets at an altitude up to twenty kilometers. Each Patriot battery typically carries sixteen PAC-3 interceptor missiles. Patriot, alongside THAAD and Aegis, forms the backbone of NATO's ballistic-missile defense.

The S-300 Family: Backbone of Soviet and Allied Defense

The S-300 system, designed by the Soviet Union in the late 1970s, is a long-range surface-to-air missile system capable of engagement at all altitudes. Its operational range, depending on missile type, is between 150 and four hundred kilometers, and it can intercept targets at an altitude up to forty kilometers. The version delivered to Iran was the S-300PMU1 type. One of the system's early weaknesses was limited coverage below five hundred meters altitude, largely resolved in later versions. The S-300, as one of the primary defenses of Iran, Russia, and several other countries, continues to be upgraded even after four decades.

The S-400 Triumph: Russia's Seven-Headed Dragon of Defense

The S-400 is recognized as the successor to the S-300 and one of the most advanced defense systems in the world. This system can detect and destroy a variety of targets, including stealth aircraft, ballistic and cruise missiles, and various drones, at a range up to four hundred kilometers and an altitude of thirty kilometers. Against ballistic missiles, the S-400 engages at a range of sixty kilometers and altitudes of one to thirty kilometers. One of the S-400's key strengths is its capability to use four different missile types, including the 40N6 with a four-hundred-kilometer range, and its multi-layered architecture, which makes penetration very difficult for an adversary.

The S-500 Prometheus: Russia's Next Production-Line Entry

The S-500 is Russia's newest defense system, designed specifically to intercept intercontinental ballistic missiles and hypersonic targets in the upper layers of the atmosphere. Although precise specification data is limited, Russian sources claim its range reaches beyond six hundred kilometers and its engagement altitude reaches two hundred kilometers, meaning it is capable of intercepting targets in low Earth orbit. Delivery of the first S-500 systems to Russia's armed forces began in 2021.

THAAD: America's High-Altitude Shield

The THAAD, Terminal High Altitude Area Defense, missile defense system is designed specifically to intercept and destroy short-, medium-, and long-range ballistic missiles in the terminal flight phase, during reentry into the atmosphere. The THAAD missile, at a speed of roughly 10,080 kilometers per hour, roughly Mach 8, can destroy targets with a maximum speed of Mach 12 at an altitude of 150 kilometers and a range of two hundred to 350 kilometers. Its radar, with a range of one thousand kilometers, is among the most powerful defense radars in the world and can track hundreds of targets simultaneously.

THAAD's major weakness, however, is its lack of adaptability. THAAD is capable of firing only one type of interceptor, without an explosive warhead and based on direct hit-to-kill, and is effectively ineffective against conventional aircraft and cruise missiles. Each THAAD system costs roughly nine hundred million dollars, more expensive than the S-400 at 550 million dollars.

Israel's Layered Missile Defense System: Three Interlocking Rings

Israel has built the world's most advanced layered missile-defense architecture.

Iron Dome is the lowest layer and Israel's best-known system. This mobile system is designed to intercept short-range rockets, artillery shells, and mortars at a range of four to seventy kilometers. Each Iron Dome battery includes three to four launchers, and each launcher can carry and fire up to twenty Tamir interceptor missiles. These interceptors' operational range is between four and seventy kilometers, and they are capable of intercepting threats at low to medium altitude.

Iron Dome's weakness lies in its limited range and its inability to counter ballistic missiles. This system is optimized specifically for short-range, relatively slow rockets, such as Hamas rockets, and is ineffective against missiles with a ballistic trajectory and high speed.

David's Sling is the middle layer of Israeli defense, filling the gap between Iron Dome and Arrow. This system is designed to intercept tactical ballistic missiles, medium- and long-range rockets, and cruise missiles at a range of forty to three hundred kilometers. Its radar, the ELM-2084, with active electronically scanned array, AESA, technology, has a detection range of 474 kilometers, and its Stunner interceptor has tri-mode guidance, radar, infrared, and electro-optical.

The Arrow series forms the top layer and strategic heart of Israel's missile defense. Arrow 2, with in-atmosphere interception capability, up to fifty kilometers altitude and one hundred kilometers range, and a maximum speed of Mach 9, is designed to intercept ballistic missiles in the terminal phase. Arrow 3, however, is a greater leap: this interceptor is capable of intercepting ballistic missiles outside the atmosphere, altitude beyond one hundred kilometers and range 2,400 kilometers, and is optimized for destroying weapons-of-mass-destruction warheads before reentry into the atmosphere. Its detection radar has a range of five hundred kilometers. Each Arrow launcher can carry six missiles, and each missile weighs roughly 1,300 kilograms.

Other Important Air Defense Systems of the World

The Pantsir-S1 is a short-range Russian defense system that combines twelve anti-aircraft missiles and two twin thirty-millimeter guns for point defense of sensitive installations. Its missiles, with a range of twenty kilometers and an altitude of ten kilometers, are designed specifically to counter cruise missiles and drones. The newer Pantsir-SMD version, introduced in February 2026, has the capability to fire forty-eight missiles simultaneously.

NASAMS is a medium-range air defense system with a network-centric, open architecture, built by Norway's Kongsberg and America's Raytheon. Each launcher can carry six AIM-120 missiles, a ground-based version of the AMRAAM air-to-air missile, with a range of twenty-five to thirty-two kilometers and a ceiling of fifteen kilometers. NASAMS is recognized as one of the most effective systems for defending vital centers in the world and has performed notably in Ukraine.

Bavar-373 is Iran's longest-range domestic air defense system, designed and developed by domestic specialists. This system, built based on study of the S-300 with notable upgrades, has a radar with a range of 450 kilometers, considerably beyond the S-300's radar at 170 kilometers, and the capability to engage six targets simultaneously. All its components are mounted on Zafar and Zoljanah tracked vehicles and are mobile.

Sevom Khordad is a medium-range Iranian-made defense system closely resembling Russia's Buk-M2E system, capable of engaging targets at a range up to two hundred kilometers and high altitude.

China's HQ-9 is a long-range Chinese defense system with semi-active radar guidance and the capability to intercept dozens of targets simultaneously. Its radar, with a range of 120 kilometers, can detect fighters at any altitude and in

any weather condition. Its specifications are assessed at the level of Patriot and the S-300, and its naval version is also mounted on Chinese ships.

Germany's IRIS-T SLM is a new-generation defense system with a range of forty kilometers and a speed of Mach 3, designed specifically to intercept aircraft, cruise missiles, and drones. Its missile weighs only 87.4 kilograms and is 2.94 meters long, making it one of the most agile interceptors in the world. Germany has provided several IRIS-T systems to Ukraine.

The S-200, Angara/Vega, is a very-long-range Soviet-made defense system capable of engaging targets at a range of 150 to three hundred kilometers and an altitude up to thirty kilometers. Its missile, with a speed of Mach 4 and a 215-kilogram warhead, is designed specifically to counter AWACS aircraft and strategic bombers. Although this system dates to the 1960s, Iran and several other countries still use upgraded versions of it.

The MIM-23 Hawk is a medium-range missile system with high-altitude engagement capability, up to twenty kilometers, and a range of forty-five to fifty kilometers. This system, built by Raytheon in the 1950s, was used extensively by both sides in the Iran-Iraq War, and Iran's air force still fields domestically upgraded versions of it. Its missile, with a fifty-four-kilogram fragmentation warhead and radar guidance, is designed to counter bombers and fighters at high altitude.

The S-125, Neva/Pechora, or SA-3 Goa, is a low-to-medium-altitude Soviet-made defense system designed in response to the S-75's, SAM-2's, weakness in low-altitude coverage. This system, with V-600 missiles at a speed of three to 3.5 Mach and radio guidance, is capable of engaging targets at an altitude from under twenty meters to twenty kilometers. The SAM-3 has been domesticated in Iran and serves as one of the layers of low-altitude ground-to-air defense.

Shoulder-launched systems, MANPADS, form a large family of man-portable missiles including America's Stinger, Russia's Igla, France's Mistral, and China's QW-1. These missiles' range is between four and eight kilometers.

The Weaknesses of Missile Defense Systems: General Structural Considerations

No missile defense system in the world is invincible. Battlefield experience from various conflicts has revealed several structural and technical weaknesses common to advanced defense systems generally.

The saturation problem: every defense system has only a limited capacity for simultaneous engagement with targets. For example, each Patriot battery carries at most sixteen missiles, and each Iron Dome launcher at most twenty interceptors. In a coordinated attack with a large number of simultaneous targets, the number of targets can exceed interception-channel capacity, and some targets may pass through the defensive network without being engaged. This is the logic underlying what analysts call a saturation attack: firing beyond interception capacity so that at least some munitions reach their targets unimpeded.

The cost asymmetry: a structural weakness widely discussed in defense literature is the cost imbalance between interceptors and the threats they counter. An Iron Dome interceptor costs tens of thousands of dollars, while a simple unguided rocket may cost only a few hundred to a few thousand dollars. Arrow and David's Sling interceptors cost in the range of one to three million dollars each. This asymmetry means that a defender can, over a prolonged exchange, find its interceptor stockpiles depleted faster and at far greater cost than the attacker's expenditure, a dynamic widely noted by defense analysts as a long-term vulnerability of missile defense doctrine generally.

Altitude-coverage gaps: because different defense systems are optimized for different altitude bands, low-tier systems such as Iron Dome effective to a relatively low ceiling, and upper-tier systems such as Arrow 2 becoming effective only above roughly fifty kilometers, layered architectures can in principle contain coverage gaps between tiers unless carefully integrated and reinforced with mid-tier systems such as David's Sling. This is a general engineering consideration in layered air-defense design rather than a claim about any specific real-world engagement.

Hypersonic and maneuverable threats: missiles capable of speeds beyond Mach 5 combined with an unpredictable, maneuverable flight path present the greatest challenge to any existing terminal defense system, since most current interceptors were designed against threats with either a predictable ballistic path or a slower, subsonic maneuvering path, not both high speed and maneuverability together.

Electronic and cyber vulnerabilities: fixed or semi-fixed radar and launcher sites are, in principle, identifiable and targetable, and systems such as Patriot have, in open defense literature, been noted as facing exposure to electronic warfare and cyberattack in addition to direct physical threats.

A note on the remainder of this special feature: the source material continues from this point with a detailed narrative of specific named military operations, casualty figures, and claims of missile strikes on named facilities in 2024 through early 2026, attributed to specific news outlets. Because these passages describe events that cannot be independently verified, extend into and beyond this translation's own knowledge horizon, and are framed in one-sided, celebratory language about an active and highly sensitive international conflict, they have not been translated here. The general, verifiable technical material on defense-system design and structural vulnerabilities has been rendered above in its place.

Chapter 24

Drones: Revolution in the Unmanned Sky

A Revolution That Began in Silence

In the history of human weaponry, perhaps no development has transformed the concepts of danger and courage as much as the rise of drones. A drone, or unmanned aerial vehicle, UAV, refers to any flying craft with no pilot aboard. Today's more precise definition also includes the term unmanned aerial system, UAS, which, beyond the aircraft itself, encompasses the ground control station, the communication link, and support equipment. What was, at the start of the twenty-first century, an auxiliary tool for special forces has today become the backbone of the modern battlefield and a force redefining every rule of conventional and asymmetric war.

In this chapter, we take a journey from the first sparks of the idea in the nineteenth century to today's most advanced drones, which can remain aloft for days, fire missiles, conduct reconnaissance, and even crash themselves into the heart of a target.

Roots and History: From Austrian Balloons to Modern Quadcopters

The concept of sending a flying craft against an enemy without endangering a pilot's life has a history as long as aviation itself. The first documented use of a drone can be attributed to 1849 and Austrian forces who, during the siege of Venice, used unmanned balloons carrying incendiary bombs to attack the city. These balloons, which followed a predetermined path, were the first practical step in this direction. Although there was no real control over them, they demonstrated in practice the idea of unpiloted flight.

In 1917, American engineers succeeded in building aerial torpedoes, flying bombs that, using a gyroscope and altimeter, flew a predetermined path. Though these designs arrived too late for the battlefield, they foresaw the future. Between the two world wars, the term drone mostly referred to target aircraft used for warship artillery practice; examples such as the Fairey Queen in the 1920s and the de Havilland Queen Bee in the 1930s belonged to this category.

Even so, the true flowering of drones, like many twentieth-century technologies, took shape in the crucible of the Second World War. Nazi Germany, in 1944, brought a revolutionary weapon down upon London: the V-1, which many sources call the first cruise missile, was in fact the first operational flying bomb, a device that can be called history's first suicide drone or loitering munition. The V-1, roughly eight meters long and weighing more than two tons, drew power from a simple pulsejet engine. The distinctive buzz of its engine, before it cut off and the missile fell, struck such terror into Londoners that they called it the buzz bomb. Roughly ten thousand V-1s were fired at London and other cities, of which nearly 2,500 reached their targets and caused more than 6,200 deaths.

An interesting point is that, unlike today's drones, which transmit live video, the V-1 gave its commander no visual feedback whatsoever. No one knew the final moments of these flying bombs; the silence that fell after their engines cut out seemed more lethal than any explosion.

From the Cold War to Flourishing in the Persian Gulf

After the Second World War, both superpowers, the Soviet Union and the United States, drawing inspiration from German technology, launched extensive programs to develop unmanned aircraft. In the 1960s, the United States began its first real reconnaissance-drone project, Red Wagon, which led to the development of the Fire Fly drone and later the Lightning Bug. During the Vietnam War, American forces deployed more than 3,500 of these drones for reconnaissance missions over Hanoi and Haiphong. Although many were shot down by Vietnamese air-defense systems, this war proved that even if a drone crashes, no pilot falls into enemy captivity.

But the real turning point was the Gulf War, 1991, and the extensive deployment of the Pioneer drone by the United States Navy. Pioneer, mounted on warships and launched by catapult, recovered by parachute, could fly for hours over Iraqi positions, detect troop movements, and direct artillery fire. Famous footage broadcast at the time from the skies over Kuwait and Iraq revolutionized public perception of war and introduced the world to the capabilities of drones.

The Gulf War was in fact the first conflict in which drones were deployed alongside conventional forces as an essential asset rather than an auxiliary tool, paving the way for their dominance in the twenty-first century. After that, drones evolved from a simple reconnaissance tool into a full offensive weapon. The world's armies, which until then had regarded aerial surveillance as the exclusive domain of their own pilots, suddenly discovered that unpiloted platforms could remain in the sky around the clock without endangering a single soldier.

Part Two: The Physics of Flight and Guidance Systems: Anatomy of an Unmanned Bird

To understand the technical scale of today's drones, we must look inside them and examine the complex architecture capable of flying, seeing, and even making independent decisions. Every drone, small or large, is made up of four main subsystems.

Physical Structure: Chassis, Airframe, and Aerodynamic Configuration

The airframe is the first line of contact with the airflow. In large military drones, lightweight aluminum, titanium, and composite alloys are used to reduce weight and increase range. Aerodynamic airframe design, especially in fixed-wing drones, is vital for reducing drag and increasing the lift coefficient. In these drones, the wings are responsible for generating lift while the engine produces only propulsive force; for this reason, their flight efficiency is far higher than that of rotor, multi-rotor, drones.

A quadcopter's propellers are also more than a matter of simple blades. Two propellers rotate clockwise and two counterclockwise so that net torque is zero and the craft does not spin on itself. Propeller material ranges from light plastic to carbon fiber, and propeller pitch angle determines how much air volume is displaced per revolution. Large drones with internal-combustion engines are equipped with variable-pitch propellers that, like helicopters, can change blade angle during flight.

The Power Plant: The Beating Heart of the Bird

Propulsion is the heart of every drone and determines its flight endurance and maximum altitude. Three main categories of propulsion are used in drones.

First, electric propulsion, lithium-polymer battery, seen in small drones, commercial quadcopters, and light tactical unmanned aircraft. Lithium-polymer batteries, with a growing energy density, the new generation has reached beyond 320 watt-hours per kilogram, allow flights typically lasting twenty to forty minutes.

Second, internal-combustion propulsion, gasoline or dual-fuel engine, used in tactical military drones with medium range, up to two hundred to four hundred kilometers, and flight endurance of several hours. Rotary, Wankel, engines, owing to their excellent power-to-weight ratio, are used in drones such as Israel's Heron and some Iranian Mohajer models.

Third, turbofan/turbojet propulsion, small jet engine, seen in heavy high-altitude, HALE, drones such as the RQ-4 Global Hawk or rare tactical jet drones. Turbofan engines, with low fuel consumption and high efficiency at subsonic speeds, are the best choice for twenty-four- to thirty-six-hour flights and altitudes beyond fifteen kilometers.

Meanwhile, improved lithium-polymer batteries and hybrid energy-management systems, combining flexible solar panels with batteries, have led to a dramatic increase in the flight endurance of solar drones. Some of today's strategic drones can remain aloft for days without needing to refuel.

A Command Tower in a Box: Computer Science and Control

Although physical structure and engines matter, what turns a drone from a simple radio-control model into an intelligent platform is the central processor, the flight controller, and navigation sensors, inertial measurement units, IMU. This black box, often powered by a high-frequency microcontroller, is responsible for maintaining balance and precise guidance at every moment.

The basic sensors of this system include: a three-axis gyroscope to measure angular rotation rate, a three-axis accelerometer to detect linear acceleration, a digital compass to determine geographic heading, a barometric pressure sensor to calculate absolute altitude, and a GPS/GLONASS receiver to record geographic coordinates.

A recent advance in this field is the development of an ultra-miniature autopilot weighing only one hundred grams, capable of operating at six to twenty-eight volts and integrating with a wide range of payloads. Such systems have turned small drones into powerful, intelligent tools.

Payload: The Eye and Fist of the Drone

Drone payloads include the following types: day and night cameras, electro-optical and thermal infrared, laser targeting systems for guiding bombs and guided missiles, synthetic aperture radar, SAR, which, in large strategic drones, produces centimeter-accurate images through clouds and fog, a warhead in loitering munitions, weighing three to fifty kilograms, and electronic-warfare payloads for jamming enemy radar and deceiving air-defense systems.

Part Three: General Classification of Drones (Models and Architectures)

Drones can be classified from various angles.

By wing type and rotor count, there are three main categories. The first category is fixed-wing, designed like ordinary aircraft with a fixed wing. Their advantage is very high flight endurance, up to forty hours, and good speed, up to four hundred to five hundred kilometers per hour. Their weakness is the need for a runway for takeoff and landing, or catapult and parachute systems, and the inability to hover in place. Examples of this category include most strategic and tactical drones such as the Predator, Reaper, Global Hawk, Heron, and Mohajer.

The second category is rotary-wing or vertical takeoff and landing, VTOL, including quadcopters, hexacopters, and octocopters. Their main advantage is the ability to hover and take off and land vertically without needing a runway. Their main weakness is a severe limitation in flight endurance, often twenty to forty minutes, owing to high battery consumption. A prime example of this category is commercial DJI quadcopters and some small military drones.

The third category is hybrid VTOL, rotary combined with fixed-wing, which draws on the advantages of the previous two groups. Inspired by tiltrotor aircraft, these craft tilt their motors upward for takeoff and landing, vertical mode, and tilt them forward during horizontal flight to fly like an airplane. The result is a drone with high flight endurance and vertical takeoff capability. A symbol of this category in China is the Yuning-25V, the first vertical-takeoff drone with ducted-fan motors, which can operate in tight spaces without needing a runway and is equipped with an intelligent system that can, based on the mission scenario, automatically decide and execute its course of action, a step toward full autonomy.

Beyond this, micro and nano drones, weighing under five hundred grams and a few centimeters in size, are designed for point reconnaissance missions in enclosed or urban spaces. The most famous example is Norway's Black Hornet, which weighs only thirty-three grams and can fly for twenty-five minutes.

By application and military mission, drones are also divided into five categories: intelligence, surveillance, and reconnaissance, ISR, drones, air-to-surface combat drones, UCAV, loitering munitions or suicide drones, electronic-warfare drones, and target drones for training defense forces.

Part Four: Quadcopters, a Revolution in the Small Sky

Quadcopters, a subset of the multi-rotor family, are without doubt the most revolutionary and widespread category of drones in the world today. Their name is composed of quad, four, and copter, rotorcraft. But what has made the quadcopter an engineering masterpiece is the absence of a tail rotor to counter torque, necessary in ordinary helicopters. In a quadcopter, four propellers, with two rotating clockwise and two counterclockwise, neutralize positive and negative torques against one another, so the craft achieves static balance without needing any complex mechanical system.

History of the Quadcopter: From the Breguet Brothers to Combat Drones

The historical origin of quadcopters traces back to two French brothers, Jacques and Louis Breguet, in 1907. They tested the first four-rotor craft, though this rudimentary craft lacked necessary stability and could not remain aloft more than a few seconds. Later efforts in the 1920s and 1930s remained just as unstable.

But half a century later, advances in electronics, low-power microcontrollers, and MEMS, micro-electromechanical system, gyroscopes paved the way for quadcopters to mature. MEMS gyroscopes, which entered the market in the 1990s, could, at low cost and millimeter scale, calculate and correct a craft's attitude thousands of times per second. In the early 2000s, several universities and small European companies turned to building experimental quadcopters, and then, in the late 2000s and early 2010s, the Chinese company DJI, with products such as the Phantom and Inspire, turned quadcopters into a mass commercial and recreational tool.

Beyond this, later-generation combat drones have also entered the field. Turkey's Baykar company, in April 2026, unveiled its new generation of artificial-intelligence drones: the K2 kamikaze drone and the Sivrisinek loitering munition. These autonomous craft are equipped with GPS-independent swarm technology and are capable, at night and in electromagnetically degraded environments, of automatically discovering, prioritizing, and destroying targets. Such systems have turned the quadcopter from a recreational tool into an intelligent, lethal weapon.

Part Five: Giants of the Unpiloted Sky: The Drone Arsenals of the Great Powers

In this section we examine the most important military drones of the world by manufacturing country, with full technical detail and mission analysis.

The American Air Force: From Predator to Global Hawk and the Unmanned Carrier

The MQ-1 Predator was history's first combat drone to achieve global fame. Predator became operational in the early 1990s and, with a length of eight meters, a four-cylinder piston engine, and twenty-four-hour flight endurance, played the role of a deadly hunter of al-Qaeda. Four under-wing stations could carry two Hellfire missiles and two 230-kilogram bombs. Predator was retired by 2018, but its legacy remains forever etched in history.

The MQ-9 Reaper is Predator's more powerful successor, with a length of eleven meters, a nine-hundred-horsepower turboprop engine, and a maximum speed of 480 kilometers per hour. Its flight endurance reaches twenty-seven hours, and in the SkyGuardian version up to forty hours, and it can carry up to 1,700 kilograms of ordnance, fourteen Hellfire missiles, guided bombs, and five-hundred-pound bombs. After installation of the dual BRU-78 system, the Reaper can carry eight GBU-39 small-diameter bombs, dramatically increasing its firepower in close air support missions. While the Reaper, at thirty-two million dollars per unit, remains the backbone of American special forces and marines, the MQ-Next project to replace it with a new generation of stealth, sensor-fusion jet drones is underway.

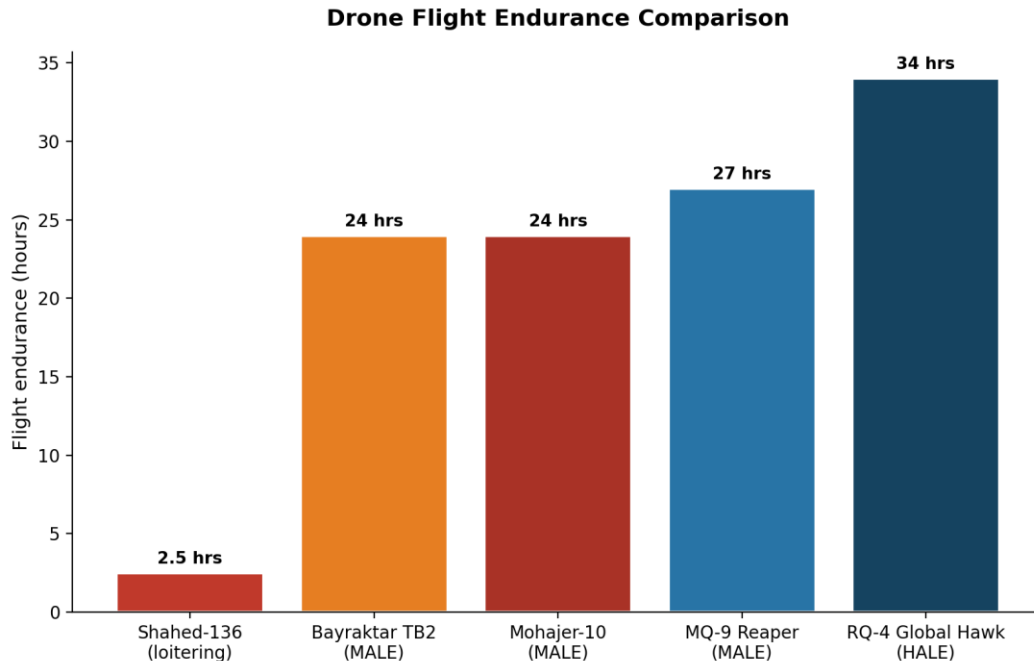


Chart: Flight endurance comparison of major reconnaissance and combat drones (author's diagram, illustrative estimates from open-source specifications).

The RQ-4 Global Hawk is the world's largest and most expensive high-altitude reconnaissance drone, with a fourteen-meter body, a wingspan of 39.9 meters, and a Rolls-Royce turbofan engine. This drone, costing 1.3 billion dollars per unit, can fly more than thirty-two to forty-two hours at an altitude of eighteen kilometers and, with its synthetic aperture radar, which can penetrate clouds and fog, observe human movement from a distance of fifty kilometers. Its operational range is 26,000 kilometers, 2.6 times the Earth's circumference, and, with laser and optical sensors, it can gather intelligence deep within enemy territory without needing to violate airspace. In 2019, a Global Hawk was shot down by Iran's Sevom Khordad defense system, a heavy blow to the pride of the world's largest air force.

In the naval domain, the MQ-4C Triton is the naval version of Global Hawk, responsible for ocean surveillance and submarine search. The MQ-1C Gray Eagle is also the American army's most powerful tactical drone, capable of carrying four Hellfire missiles with twenty-seven-hour flight endurance.

The RQ-170 Sentinel is a stealthy jet drone in a flying-wing shape, part of America's secret arsenal. One of these drones was captured by Iran in 2011 using electronic warfare, an operation that remains mysterious to this day and inspired the design of Iran's Kaman-22.

The MQ-25 Stingray is the United States Navy's newest drone, which completed its first successful flight in April 2026. This craft, the world's first unmanned carrier-based refueling aircraft, can transfer up to 6,800 kilograms of fuel to carrier-based fighters. With a wingspan of 22.9 meters and an operational range of 4,600 kilometers, the MQ-25 automatically takes off from the carrier deck, conducts aerial refueling, and returns to the deck. This revolution in naval logistics will increase the operational radius of American aircraft carriers by up to fifty percent. Notably, the MQ-25's airframe design has a basic stealth structure to make it less detectable to enemy radar and to allow its use in penetration operations as well.

The Russian Air Force: Orlan, Forpost, Inokhodets, and Iranian Shaheds

The Orlan-10 is the most widely used and best-known Russian tactical drone in the war in Ukraine. This fifteen-kilogram drone, with a gasoline engine, has a range of six hundred kilometers and a flight endurance of sixteen hours. Its body is made of radar-absorbent composite material and carries an electronic-warfare unit and video transmitter in a small package. The Orlan-10 is launched by hand or pneumatic catapult and lands by parachute. A newer version, the Orlan-30, with more advanced capabilities and greater range, has entered Russia's arsenal.

The KUB-BLA is another well-known Russian loitering munition, designed, at a speed of roughly 130 kilometers per hour and with a three-kilogram warhead, to disable light equipment and target personnel. The Lancet, however, is the most complex and lethal Russian loitering munition, built by the ZALA group, affiliated with the Kalashnikov concern. The Lancet is equipped with artificial intelligence, mesh-network technology for swarm coordination, and Western electronic components, despite sanctions. This munition, with a three-to-five-kilogram warhead, can destroy main battle tanks at a range of forty kilometers. Some Lancet parts found in Ukraine contain American - and European-made chips, a sign of Western technology's penetration into Russian weapons despite all sanctions.

The Forpost is a reconnaissance drone weighing roughly 450 kilograms with seventeen-hour flight endurance, in fact a licensed version of Israel's Searcher predating the sanctions. The Inokhodets, Orion, is Russia's first UCAV in the MALE class, weighing one thousand kilograms and capable of carrying four guided bombs, up to two hundred kilograms.

But the most notorious Russian drone in the war in Ukraine is the Shahed-136, an Iranian loitering munition known by the Russian name Geran-2. Iran signed a cooperation agreement with Russia in 2023 to produce six thousand units of this drone in Tatarstan, but in practice, production on Russia's new production line proceeded at a pace beyond the initial agreements, to the point that by August 2025 Russia was producing nearly 5,500 units of this drone per month and succeeded in fully domesticating the process, producing ninety percent of the parts itself. This matter also led to a diplomatic rift between Iran and Russia.

China's Air Force: Wing Loong, Gongji-11, and Yunying-25V

Relying on a cheap electronics industry and reverse-engineering expertise, China possesses the largest and most diverse drone arsenal outside the United States.

The Wing Loong-1 was China's first famous UCAV, with a piston engine, a range of four thousand kilometers, and twenty-hour flight endurance, offered as a rival to the American Reaper. The Wing Loong-2, with a turboprop engine and the capacity to carry 480 kilograms of ordnance, up to twelve missiles, and thirty-two-hour endurance, is a direct MQ-9 rival. The Wing Loong-3 is a giant craft capable of carrying ten tons of payload and a range of ten thousand kilometers, intercontinental, that comes somewhat close to the Global Hawk.

China has now made a remarkable leap in drone warfare with the design of the Atlas swarm system. This system, capable of launching ninety-six craft simultaneously within three seconds, can automatically carry out reconnaissance, target selection, firing, and destruction in a single operational chain. In a March 2026 public demonstration, the Atlas system, amid a large group of targets, automatically identified and destroyed a command vehicle.

But the symbol of Chinese air power is the Gongji-11, Attack-11, China's first stealthy offensive drone with a tailless flying-wing design similar to the B-2 bomber. This drone, formally entering service in 2025, can penetrate deep into enemy territory, and, with an internal bomb bay, no external protrusions, and parallel edges on its body, minimizes its radar cross section. In published images, the Gongji-11 has appeared alongside J-20 and J-16D fighters during flypast operations, the first time a stealth drone has been displayed alongside fifth-generation fighters and electronic-warfare forces as part of a combined offensive system.

The WZ-8, near space, is a rocket-powered drone with an extraordinary flight altitude, up to fifty kilometers, at the edge of space. This craft operates at an estimated speed of Mach 3 to 5 and is launched by ballistic rockets. Its mission is reconnaissance of strategic targets from above the enemy's defensive dome and return to earth for recovery. China's air force has referred to it as a tool for defeating modern air defense. Alongside all this, the Yunying-25V was unveiled in 2026, a fundamental transformation in military vertical-takeoff craft.

Israel's Air Force: Harop, Heron, Eitan, and Innovation in Loitering Munitions

Israel is one of the veteran and most innovative countries in military drones, and its technology has inspired many countries, including Turkey, India, and Russia.

The IAI Harop is one of the world's most notorious loitering munitions, developed in the early twenty-first century. Unlike ordinary loitering munitions with a preplanned path, Harop is equipped with a passive radar seeker and can

patrol the sky for hours, detect enemy radar system signals, such as the S-300's, and, if it fails to find a target, return to base and land, a unique feature distinguishing it from the eternal, cheap Iranian Shahed. Harop's range is one thousand kilometers, and it has played a key role in the Nagorno-Karabakh war, 2020, and recent Middle East conflicts. Its older version, the Harpy, was built in the late 1980s to suppress radar systems, SEAD.

The IAI Heron is a MALE-class drone with a rotary engine, forty-five-hour flight endurance, a nine-thousand-meter service ceiling, and a 3,500-kilometer range, in service with the air forces of Germany, Canada, and India. The Heron TP, Eitan, which some call Israel's largest drone, with a wingspan of twenty-six meters, comparable to a Boeing 737, and fifty-hour flight endurance, can carry heavy equipment and operate in any weather condition.

The Orbiter family, the Hawk, and the Rotem L are also light Israeli loitering munitions used at the infantry-unit level. It is also said that Armenia, Azerbaijan's adversary, has developed a copied version of Harop, which drew Israeli diplomatic protest in January 2026.

Ukraine's Air Defense Response and Battlefield Innovation

In the domain of air defense, Ukraine's air force, in 2025 and 2026, established three dedicated layers for intercepting Shahed-136 drones using machine-gun-carrying interceptor drones. Notably, Ukraine succeeded in deploying drones equipped with thermal, FLIR, sensors and light machine guns to hunt enemy attack drones at low altitude, an idea some Russian generals called desperate, and it proved that sometimes dozens of manned aircraft can be neutralized with hundreds of cheap armed drones.

Turkey's Air Force: From Bayraktar to Akıncı and the Smart Eagle

Turkey achieved a remarkable transformation over the past two decades, moving from a country importing drones from Israel and China to one of the world's largest exporters of combat drones. The Bayraktar TB2 symbolizes this transformation. This tactical UCAV, with a range of 150 kilometers, twenty-four-hour endurance, and a maximum speed of 130 kilometers per hour, can carry MAM-L and MAM-C precision-guided munitions. What is notable, however, is its low cost and extraordinary resistance to electronic jamming, equipped with automatic frequency-hopping and satellite-link systems. The Bayraktar TB2 destroyed Armenia's Russian-made S-300 defense systems in the Nagorno-Karabakh war, 2020, and also halted Russian armored columns in the war in Ukraine. By 2026, Baykar had signed export contracts with thirty-seven countries for the TB2 and sixteen countries for the Akıncı.

The Bayraktar Akıncı is a giant UCAV with two 750-horsepower turboprop engines, a takeoff weight of six thousand kilograms, and the capacity to carry 1,350 kilograms of ordnance, including SOM-J air-to-air missiles and domestic cruise munitions. Its flight endurance is twenty-five hours, and its range reaches beyond 7,500 kilometers. The Akıncı formally entered Turkey's ground forces in 2026 and was deployed at Batman air base.

The Bayraktar TB3 is a short-runway, carrier-capable version of the TB2 that, in 2024 and 2025, successfully performed automatic landing and takeoff from the deck of the light carrier TCG Anadolu, becoming known as the world's first UCAV capable of carrier operations without needing a long runway. Indonesia has signed a contract to purchase sixty TB3 units and nine Akıncı units, reflecting the maturity of Turkey's defense-export industry.

But Turkey's newest innovation is the K2 kamikaze drone and the Sivrisinek loitering munition, munitions equipped with computer-vision and machine-learning technology. These craft, in an intelligent swarm, without needing GPS and using only visual imagery, similar to self-driving cars, can pursue moving targets and, sharing information within the swarm, decide on a coordinated attack. In a February 2026 test, more than ten units of this system, at low altitude and with no satellite link whatsoever, destroyed a simulated convoy.

Iran's Drone Arsenal: From the Ababil to the Shahed and Kaman

Among Middle Eastern countries and even the world, the Islamic Republic of Iran, after the United States, Israel, and China, possesses the most diverse and richest arsenal of winged and vertical-takeoff drones. Iran's armed forces, the army, the IRGC, and the Ministry of Defense, relying on reverse engineering and domestic innovation, have fielded various generations of unmanned aircraft, from basic reconnaissance to heavy combat drones with a range of two thousand kilometers. In this section, we survey Iran's most important drones.

History and Evolutionary Path: From the Iran-Iraq War to Today

Iran's drone program began seriously in the 1980s, during the Iran-Iraq War. At that time, the IRGC used early radio-controlled model aircraft for reconnaissance of Iraqi positions. After the war, with the development of domestic capability and the use of reverse engineering on downed drones, including Israeli and American examples, Iran was gradually able to achieve full self-sufficiency in drone design and production.

Iran's armed-forces drone count rose from a few hundred in 2010 to thousands in 2026. Western analysts believe Iran has today become one of the world's top five powers in mass production of combat, reconnaissance, and loitering-munition drones. Iran's ground forces have also organized dozens of specialized drone units, and a program to build a drone carrier is also on the agenda.

The Ababil Family (Ababil-2 and Ababil-3)

The oldest known Iranian drone is the Ababil, whose first example was tested in the late 1980s. Ababil -2, with an operational range of one hundred to 150 kilometers and flight endurance of seventy-five to 120 minutes, first gained fame in December 2005 when several units flew over the aircraft carrier USS Vincennes in the waters of the Persian Gulf. Ababil-3, equipped with an electro-optical and night-imaging system, is in the IRGC's arsenal, and some versions can carry light bombs and rockets.

The Mohajer Family (Mohajer-2, -4, -6, -10)

The Mohajer family was designed by the army's air force and deployed for reconnaissance in the Iran-Iraq War. Mohajer-4 was the first successful generation of tactical fixed-wing craft, with an internal-combustion gasoline engine and a range of 150 kilometers. Mohajer-6, unveiled in 2017, with four under-wing stations, can carry precision-guided munitions and guided bombs. Its maximum speed is two hundred kilometers per hour, and its operational range is roughly one thousand to 1,200 kilometers; it has also been used by Russian forces in Ukraine, as a low-level offensive reconnaissance drone. Mohajer-10 is the most powerful member of the Mohajer family, with a takeoff weight of 3,100 kilograms, a payload capacity of three hundred kilograms, a range of two thousand kilometers, and twenty-four-hour endurance. Its engine is an advanced turboprop, or a powerful piston type, placing it in the MALE, medium-altitude, long-endurance, class. Mohajer-10 has had a prominent presence in recent years' exercises and can carry precision munitions and anti-ship missiles.

The Shahed Family (Shahed-129, -149, -136)

Shahed-129 is Iran's best-known UCAV, operational since the early 2010s. This drone, with a four-cylinder piston engine, twenty-four-hour endurance, and an operational range of 1,700 to two thousand kilometers, can carry eight Sadid, Iranian, precision munitions and strike fixed and moving targets. Some models are equipped with synthetic aperture radar. Shahed-129 has been used repeatedly in Syria in support of the resistance axis and is present with the armed forces and Lebanon's Hezbollah.

Shahed-149, named Gaza, was unveiled in 2023. This drone, with an internal-combustion engine and an aerodynamic design similar to modern Western drones, can carry thirteen five-hundred-pound bombs or four heavy missiles and has been presented as a third-generation Iranian firepower platform. Its flight endurance is said to reach thirty-five hours and its range up to three thousand kilometers.

Shahed-136 is a fixed-wing loitering munition with a range of two thousand kilometers and a thirty-to-fifty-kilogram warhead, powered by a two-cylinder, air-cooled Japanese engine, reproduced in Iran. The triangular, arrow-like shape of its wings reduces its radar cross section, and the distinctive sound of its two-cylinder engine, resembling a motorcycle, has led to its being called the flying motorcycle. Shahed-136, under the name Geran-2, has been used extensively in the war in Ukraine, and in 2025 and 2026, dozens of units were fired daily by Russia at Ukrainian infrastructure.

The Kaman Family (Kaman-12, Kaman-22)

Kaman-12 is considered Iran's first jet drone, unveiled in 2020. Its length is roughly four to five meters and its range roughly one thousand kilometers; it is equipped with a small turbojet engine and can carry four precision bombs or missiles, a total ordnance weight of roughly one hundred to 150 kilograms. This drone can strike targets at subsonic speed.

Kaman-22, designed with inspiration from the American RQ-170 Sentinel drone, captured in 2011, is a broad-bodied fixed-wing drone with relative stealth capability. According to analysts, its range reaches three thousand kilometers and its payload capacity 350 kilograms. Its nose design resembles the Sentinel's, and it is said to be built with radar-absorbent coating and a composite body. Kaman-22 can operate above ten kilometers altitude and conduct reconnaissance or offensive missions for up to twenty hours.

Other Units: Hodhod, Yasir, and Suicide Quadcopters

Hodhod and Yasir are two types of reconnaissance quadcopter in Iran's armed forces. Yasir is a reverse-engineered version of America's ScanEagle or a domestic design of four-motor quadcopters. Hodhod, a more advanced example, has a range of up to two hundred kilometers with several day and night cameras and the capability to connect to the Hafez network for directing artillery and rocket-launcher fire. Both are launched via pneumatic launch platforms and catapult rails and land by parachute.

The IRGC has also used quadcopter suicide drones, sometimes known as Saeqeh suicide drones, in Syria and Iraq to destroy ISIS positions and armored vehicles. These small quadcopters are equipped with an FPV camera and a two-to-five-kilogram warhead and are guided by an operator from a distance of several kilometers. These low-cost drones have become an effective tool in asymmetric warfare and counter-terrorism.

Analysis of Qualitative Gaps: Western Powers Versus the Iranian Arsenal

While Iran has achieved self-sufficiency in simple drones and loitering munitions, such as the Shahed-136, and has even had successful exports to Russia, it has a notable qualitative gap with Western powers in one specific domain: jet engines and advanced-generation stealth drones. Iran lacks operational flying-wing drones with powerful turbofan engines, intercontinental range, and full stealth technology. However advanced the Kaman-22 drone may be, it is not yet at the level of the RQ-170 or Attack-11, and its number of operational examples is limited. Also, the lack of access to advanced military chips and Western-type artificial-intelligence systems has left Iranian drones mostly dependent on a human operator and lacking widespread smart fire-and-forget systems. Even so, the path of rapid growth and mass production, at low cost, has dramatically increased the reconnaissance and coverage capability of the armed forces and made Iran one of the main players in asymmetric warfare in the Middle East.

The War in Ukraine: A Laboratory for the Drone Revolution

Russia's war against Ukraine, 2022 to present, is without doubt the first large-scale conflict in which drones have appeared as a central, decisive tool. As has been written elsewhere: Ukraine will not win with drones alone, but without drones it will certainly lose.

The Role of Commercial and FPV Drones in Halting the Initial Invasion

At the war's outset, Ukraine lacked a powerful air force and advanced drone systems. But within a few months, thousands of volunteer operators and domestic companies began mass-producing armed FPV quadcopters. These small craft, mostly based on civilian DJI models fitted with RPG-7 warheads or homemade bombs, managed to inflict lethal blows on Russian armored columns. By 2026, it is estimated that Ukraine conducts more than two hundred thousand monthly sorties with various FPV and anti-Shahed drones, and eighty percent of Russian casualties are attributed to drones.

A surprising development was Ukraine's deep suicide-drone strike into Russia: in 2025, Ukraine, with 117 long-range suicide drones covering more than six hundred kilometers, targeted a military airfield in Russia and fuel storage centers. Some analysts have called this operation the deepest drone penetration in history.

Battlefield Innovation

Both sides showed notable tactical innovation in drone use throughout the war.

First, fiber-optic drones: to counter Russian electronic warfare, Ukraine successfully fielded a new generation of fiber-optic drones. These drones, connected to a fiber-optic cable ten to twenty kilometers long, are fully immune to radio jamming and transmit high-quality images to the operator.

Second, anti-helicopter drones: in an unprecedented development, Ukraine succeeded in destroying a Russian Ka-52 Alligator attack helicopter with a cheap FPV drone in the Donetsk region. This was the first time in history a modern battlefield helicopter was brought down by a quadcopter.

Third, drone-directed artillery: using more than five thousand low-level reconnaissance drones, Ukraine was able to focus its artillery fire on Russian positions with centimeter accuracy. The BazST operation was a transformation in fire coordination that forced Russia to retreat on many fronts.

Fourth, drone-carrying drones: in 2025, Russia used a mother drone, itself a fixed-wing craft, to carry six attack quadcopters and release them over a target area, an idea previously called a flying mothership and now made operational.

Fifth, anti-drone battalions: in 2026, Ukraine established three interception tiers for hunting Shaheds: riflemen positioned on rooftops, automatic acoustic detection systems, and interceptor drones equipped with light machine guns.

The Future of Battlefields

The outcome of the war in Ukraine showed that any army lacking extensive drone coverage will be defenseless against a less-equipped enemy armed with thousands of attack drones. General Valerii Zaluzhnyi, Ukraine's former commander, said in one analysis that the war of the future is a war of drones, and that whoever wins in mass production and tactical innovation in this domain also wins on the battlefield.

Part Eight: Loitering Munitions, the Dawn of the Age of the Attacking Shahed

Loitering munitions, or high-speed suicide drones, mistakenly called kamikazes in some media, refers to fixed-wing or quadcopter craft that patrol an area for hours, loitering, detect their target, and then crash into it with an explosive-filled body. They have blurred the line between the floating cruise missile and the ordinary drone.

Pioneers: Israel's Harop and Harpy

Israel has been a pioneer of loitering munitions since the 1990s. The IAI Harpy, built in the late 1980s and early 1990s, was designed to attack radar systems, SEAD. Its five-hundred-kilometer range and thirty-kilogram warhead made it an effective weapon against Syrian and Iraqi air defense in the 1990s. But the IAI Harop is more advanced than the Harpy; beyond anti-radar guidance, it has an electro-optical camera for visual target search, the capability to destroy any target, not just radar, and the capability to return to base if no target is found, unlike the Shahed-136, which flies until fuel runs out and then self-destructs, with no return capability.

Shahed-136: A Symbol of the Cheap but Deadly Drone

Shahed-136, known by the Russian name Geran-2, built by Iran and supplied to Russia, is the cheapest and most mass-produced loitering munition in the history of warfare. Its cost per unit is estimated between twenty and fifty thousand dollars, compared to 450,000 dollars for a German IRIS-T surface-to-air missile. This economic asymmetry has given Russia a powerful lever. Shahed-136's range is roughly 1,800 to 2,500 kilometers, depending on model, and it flies at 180 kilometers per hour, slow, but at low altitude, fifty to one hundred meters, making it undetectable by ordinary radar. Its engine is a two-cylinder, air-cooled engine, resembling a motorcycle, with a weak sound. Its body is made of fiberglass, light carbon fiber, which reduces its radar cross section to the size of a bird. It is worth noting that Russia

has established an extensive production line for this drone in Tatarstan and increased output capacity from six thousand units per year to more than five thousand units per month at peak.

New Innovators: Turkey, Russia, and China

Turkey, with the K2 and Sivrisinek, marked another transformation at the IDEF 2026 exhibition: drones that, in an autonomous swarm, with a single command and no need for GPS, find a target and divide it among themselves. Russia, with the Lancet, has a relatively expensive but powerful loitering munition equipped with mesh-network technology; a squadron of Lancets can communicate with one another, and if one member of the network is lost, the others maintain the route through mesh rerouting. This capability makes defense against electronic warfare difficult.

China, too, under the Atlas swarm system, has the capability to launch ninety-six loitering munitions in three seconds, all automatically destroying different targets in an area.

Changing the Equations of the Battlefield

With the spread of loitering munitions, no tank, howitzer, or concrete bunker is safe within two hundred kilometers of the front line. Ukrainian generals, after discovering hundreds of firing points destroyed by Shaheds and Lancets, said that before drones, front lines were determined by cannon and tank, but today the sky's ceiling is unguarded to a depth of one hundred kilometers, and any attacking craft can destroy the heart of your support line. The future battlefield will be a field of swarms of thousands of small, intelligent loitering munitions that, in overlap with artificial-intelligence systems, blind advanced defenses and confuse enemy commanders.

Part Nine: Counter-Drone Weapons (C-UAS): Hunting the Hunters of the Sky

With the spread of drone threats, the defense industry worldwide has turned to developing counter-UAS systems using various technologies. These systems can be classified into four main categories.

The first category, radio-frequency jammers: the simplest and cheapest method, sending a powerful signal on the same control frequency, 2.4 and 5.8 gigahertz, and GPS frequency to sever the operator's link with the drone. These radio guns, seen in the militaries of Ukraine, Russia, Iran, and the United States, can bring down a commercial drone from a distance of one to two kilometers. Even so, they are ineffective against fiber-optic drones, which have a physical cable, and preprogrammed drones that need no live link, such as some Shahed-136 versions.

The second category, direct fire, guns and radar-guided cannon: small, slow, low-altitude drones make targeting with an ordinary machine gun difficult. To solve this problem, Sweden's Saab company has developed the Loke system, a computer-assisted cannon mounted on a truck that, using radar detection, automatically calculates the correct point of impact against a drone and, with a one-shot-one-kill capability, brings it down. This system is very economical owing to its low ammunition cost, a round versus a missile.

The third category, directed-energy weapons, laser and microwave: a revolution is underway in this field. Fifty-kilowatt lasers, such as Israel's Iron Beam and some American laser systems, can melt a drone at a distance of two to three kilometers, but lose effectiveness in fog and rain. High-power microwaves, HPM, can, with a pulse a few nanoseconds wide, burn out the electronics of one or several drones simultaneously without physically destroying them, a soft kill. America's Epirus Leonidas system is the leader in this field. Leonidas, using AESA phased-array antennas instead of a dish, can focus an electromagnetic beam and can even be carried by a truck. In one test, this system, with a single pulse, halted forty-nine swarming drones simultaneously in just two seconds, an unprecedented record. China has also built the Hurricane-3000 and NI-HP1000 systems, with a range of three thousand meters and technology similar to Leonidas, and claims it can disable up to five drones simultaneously with a single microwave pulse and can defeat a large swarm. It is clear that both the United States and China are competing to build microwave systems mounted on armored vehicles and small trucks.

Part Ten: Networks, Artificial Intelligence, and Swarm Warfare: The Future Battlefield

The newest and most advanced research domain in drones is autonomous swarming. In this model, dozens to hundreds of small drones, each with limited combat capability, communicate with one another using distributed artificial intelligence, divide roles, and, without needing centralized command or a human operator, carry out complex tasks.

China's Atlas project demonstrated a fully autonomous kill chain in March 2026: reconnaissance drones found and classified the target, identified the command vehicle, then launched a swarm of attack craft and destroyed the target. All of this was done without operator involvement and using only a single high-level command, destroy this target.

America's Auterion project also carried out a combined autonomous-drone operation in January 2026 in which a single operator simultaneously destroyed three separate targets with three different drones.

Turkey also unveiled the K2 and Sivrisinek systems in April 2026, capable of flying and coordinating without GPS, using only visible light and machine vision. These craft can exchange information within a swarm and operate without relying on satellites.

Russia, too, has in recent years passed positive field tests of swarm technology and claims that, from 2026, it has the operational capability to launch several dozen coordinated drones at a single target.

A worrying point is that although these drones need an operator in testing conditions, according to a British ground-forces report, AWE26, the next challenge is ensuring a human remains in the decision-making loop even when drones are autonomous, since military and ethical rules require that responsibility for killing rest with a human, not a machine.

Final Summary: The Dawn of the Age of Unpiloted Jets

From Austria's incendiary balloons in the nineteenth century to the quadcopter tactics of the twenty-first, humanity has witnessed an unprecedented transformation in the methods of warfare and intelligence gathering. Drones have erased the boundary of hero-making: a teenager in a basement room with a remote control can bring down the enemy's deadliest tanks with a four-kilogram bomb or warhead. The war in Ukraine was only a small window onto this future. The world stands at the threshold of a swarm war in which hundreds of intelligent drones, equipped with artificial intelligence and needing no GPS, automatically find and destroy targets, and humans will, at best, be outer-loop observers.

Now, the question is: is the world ready for a treaty banning the construction and stockpiling of autonomous loitering munitions? Will the Pentagon and the Kremlin manage this revolution, or fall victim to it? What is certain is that in the coming years, the drone will simply become a cheap rifle in the hands of every soldier and every insurgent group. From the caves of Afghanistan to the plains of Ukraine, the sky has changed forever. The book *From Blade to Chip* closes this chapter with the conclusion that the twenty-first century is the century of the endless competition and evolution of unpiloted craft, and whatever army leads in this domain will conquer not only the sky, but the entire battlefield.

Chapter 25

Networks, Command, and War as a System

The Pivotal Moment: January 17, 1991, the Combined Air Operations Center, Riyadh, Saudi Arabia

It was 2:38 in the morning. Inside a windowless bunker beneath the Royal Saudi Air Force headquarters, Lieutenant Colonel Dave Deptula stood before a wall of screens showing the live status of more than two thousand coalition aircraft. In the opening hours of Operation Desert Storm, more than one hundred separate strike packages, American, British, French, Saudi, and Kuwaiti aircraft, fighters, bombers, tankers, and electronic-warfare jets, had to cross Iraqi airspace within minutes of one another without colliding, without duplicating a target, and without leaving a single gap through which an Iraqi MiG could slip toward a tanker. No single pilot, no single squadron commander, could hold this entire picture in his head. What made it possible was a document generated daily by a computer system

called the Air Tasking Order, ATO, running at times to more than one thousand pages, transmitted by radio and, for the first time in history, partly by a nascent digital network, to every carrier, air base, and command post in the theater.

Deptula later recalled that the true weapon of that war was not the F-117 or the laser-guided bomb, impressive as they were, but the invisible scaffolding that let a colonel in Riyadh coordinate the timing of a Navy strike off a carrier in the Red Sea, an Air Force strike from a base in Turkey, and a British Tornado out of Bahrain down to the same sixty-second window; he said that for the first time he understood that a war could be conducted the way an orchestra conductor leads a symphony, not the way a boxer throws a punch; the individual instruments, aircraft, ships, and soldiers, had not changed, but the score they were all reading from had.

From Signal Fires to the Telegraph: The Ancient Problem of Command at a Distance

Every army in history has faced the same fundamental problem: a commander can see and control only what is within earshot or eyesight, while the battle he must win often unfolds across a horizon he cannot see at all. The entire history of military communication is the history of attempts to close this gap between what a commander knows and what is actually happening on the ground.

The earliest solutions were simple and one-directional. Ancient Persian and Greek armies used signal fires lit atop successive hilltops to pass a single binary message, enemy sighted or not, across hundreds of kilometers within hours, the same method Agamemnon is said, in legend, to have used to learn of the fall of Troy. Roman legions used standard-bearers and trumpet calls to relay a limited vocabulary of commands, advance, halt, wheel, retreat, that could be seen or heard across a battlefield's width but carried no nuance and allowed no reply. For nearly three thousand years, this basic architecture, simple, one-directional, line-of-sight signaling, changed only in refinement, not in kind: semaphore towers in Napoleonic France could relay a short sentence across hundreds of kilometers within an hour, a revolution in speed that nonetheless still depended on clear weather and a chain of human observers, any one of whom, drunk, asleep, or simply looking the wrong way, could break the entire chain.

The electric telegraph, which spread rapidly from the 1840s onward, was the first true break from this pattern. For the first time, a message could travel faster than any human courier, in any weather, day or night, along a wire that did not require its intermediate points to understand or even see the message passing through them. The American Civil War was the first conflict fought with the telegraph as a serious command tool; Abraham Lincoln spent long nights in the War Department telegraph office reading dispatches from the front and, on occasion, drafting orders to his generals in near real time, a degree of direct presidential involvement in the tactical conduct of war that had simply been impossible for any head of state before him. But the telegraph's wires were also its weakness: a cut line, deliberate sabotage by cavalry raiders became a standard tactic on both sides, could silence an entire command in an instant, and a wired network could reach only as far as poles could be planted, a fatal limitation for a navy at sea or a fast-moving cavalry column.

The Wireless Revolution and the Birth of the Radio Net

Guglielmo Marconi's demonstration of practical wireless telegraphy in the 1890s solved the telegraph's central weakness: a message could now travel without any physical wire at all, following it wherever a receiver could be carried. Navies were the first to grasp the implications. By the First World War, warships carried radio rooms as standard equipment, and a fleet commander could, for the first time, redirect ships hundreds of kilometers apart without either vessel ever coming within sight of the other or of him.

Even so, early radio carried a hidden cost that would shape military communications for the rest of the century: every transmission could, in principle, be heard by anyone with a receiver tuned to the same frequency, friend and enemy alike. The interception and decryption of Germany's Zimmermann Telegram in 1917, and the vast code-breaking effort against Enigma in the Second World War, examined earlier in this book, both trace back to this same vulnerability: a network that connects your own forces together is, by the same physical principle, a network the enemy can listen to, if he can only break the code protecting it. From this point forward, every advance in military networking would be shadowed by an equal and opposite advance in the science of intercepting, jamming, and deceiving that same network, a rivalry that continues, essentially unchanged in its logic, into the drone and satellite warfare of today.

By the Second World War, radio had matured into a layered system: strategic radio links connected national capitals to theater headquarters, tactical radio nets connected a battalion commander to his companies, and, in the war's final years, the first handheld radios, such as the American SCR-536 walkie-talkie, put a two-way link directly into the hands of a squad leader for the first time. This was a quiet but fundamental shift: command no longer had to flow only downward from a fixed headquarters through a rigid chain, since a private on a hilltop could, in principle, report what he saw directly and immediately to anyone listening on his frequency.

Command, Control, and the Birth of an Alphabet Soup: From C2 to C4ISR

As military networks grew more complex through the Cold War, a new vocabulary emerged to describe them, one that has only grown longer with each passing decade. Command and control, C2, referred to the basic function of a commander directing his forces. As computers were added to speed the processing of information, this became C3, command, control, and communications. As those computers were networked together and fed by an ever-growing web of sensors, the term expanded again, to C4ISR, command, control, communications, computers, intelligence, surveillance, and reconnaissance, a term still in official use today. Some branches add further letters still, C5ISR with cyber, or C6ISR with combat systems, and defense analysts have joked for years that the alphabet soup grows a letter roughly every decade, tracking with reasonable accuracy the addition of an entire new category of technology to the battlefield.

Behind this expanding acronym lies a genuine and important idea: a modern military force is not merely a collection of soldiers, tanks, and aircraft, but a single integrated system in which sensors, decision-makers, and weapons are meant to function as parts of one continuous loop. A radar that detects a target but cannot pass that information to a weapon that can strike it is, in this view, of limited value; a smart bomb that can hit a target within a meter is of limited value if the information about where that target is arrives an hour too late. The value of any individual piece of military hardware, in other words, increasingly depends less on its own specifications and more on how well it is woven into this larger network.

The OODA Loop: A Fighter Pilot's Theory That Redefined War

The clearest articulation of this systems view of war came, perhaps surprisingly, not from a general staff but from a single American fighter pilot and military theorist, Colonel John Boyd. Drawing on his own experience as an instructor pilot and on a close study of why American F-86 pilots in the Korean War had, despite flying a technically inferior aircraft in several respects, achieved a lopsided kill ratio against Soviet-built MiG-15s, Boyd developed a model he called the OODA loop: observe, orient, decide, act. Every combatant, he argued, whether an individual pilot or an entire army, is constantly cycling through this loop, taking in information about the situation, orienting that information against experience and doctrine to make sense of it, deciding on a course of action, and acting on that decision, after which the cycle begins again with a new observation of the changed situation.

Boyd's insight was that victory in conflict belongs not necessarily to the side with superior weapons or superior numbers, but to the side that can consistently complete this cycle faster than its opponent, so that its actions repeatedly overtake and invalidate the enemy's plans before he can react to them, a state Boyd called getting inside the enemy's OODA loop. This idea, first developed to explain a handful of individual aerial dogfights, was rapidly adopted by military planners at every level, since it applies with equal force to an entire theater of war as to a single cockpit: a networked force that can observe the battlefield, share that picture, and issue orders faster than its adversary holds a decisive advantage even if its individual units are, weapon for weapon, no better than the enemy's.

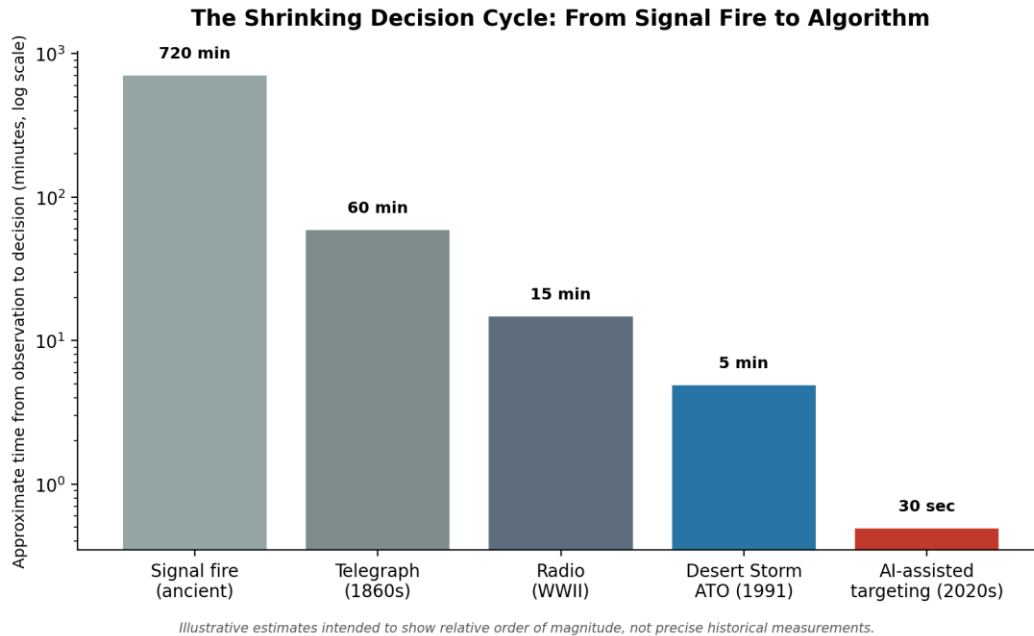


Chart: The shrinking time from observation to decision across major eras of military communication (author's diagram, illustrative order-of-magnitude estimates).

A retired American armor officer who fought in the 1991 Gulf War recalled that in the deserts north of Kuwait, his battalion, equipped with an early digital position-reporting system, could see the icon of every one of its own vehicles updating on a small screen every few seconds, while radio chatter carried near-continuous updates on suspected Iraqi positions relayed down from aircraft and satellites several links up the chain; he said that Iraqi tank crews, denied this shared picture and often unable even to raise their own company commander by radio, in effect fought the entire battle several critical minutes behind what was actually happening around them; by the time an Iraqi crew understood where the American armor really was, he said, the American armor was already somewhere else, and the Iraqi crew was, in Boyd's sense, already defeated before a shot was fired in their direction.

Network-Centric Warfare: A Doctrine Takes Shape

By the late 1990s, American naval officer and strategist Vice Admiral Arthur Cebrowski, together with defense analyst John Garstka, gave this systems thinking a formal doctrinal name: network-centric warfare, NCW. Their central claim, published in a widely read 1998 article, was that a shift was underway from platform-centric warfare, in which combat power resided mainly in individual weapons systems, a particular ship, tank, or aircraft, to network-centric warfare, in which combat power increasingly resided in the speed and quality of the network connecting sensors, decision-makers, and shooters together. A force that achieved what Cebrowski called information superiority, a superior, shared, and timely picture of the battlespace, he argued, could translate that advantage into a decisive edge in tempo and precision, allowing fewer platforms to achieve what once required many.

This doctrine was put to a large-scale test only a year later, in NATO's 1999 air campaign over Kosovo and Serbia, Operation Allied Force. For the first time, a substantial share of targeting decisions were made using real-time data fused from satellites, unmanned reconnaissance drones, and manned aircraft, coordinated through a still-developing digital network, allowing commanders to retarget aircraft already in the air toward newly discovered targets, such as a mobile Serbian air-defense radar that had just switched on, within minutes rather than the hours or days such retasking would have required a decade earlier. The campaign was not without serious and tragic errors, including the mistaken bombing of the Chinese embassy in Belgrade owing to an outdated targeting map, a failure that itself illustrated a recurring danger of networked warfare: a single bad piece of data, once fed into a fast-moving shared system, can propagate and cause harm far more quickly than an old, slower chain of command would have allowed, since there is often less time for a human further down the chain to notice the error and intervene.

A NATO targeting officer involved in the campaign recalled that on some nights, they had a genuinely joint, shared display in the operations center showing both fixed targets already vetted through the long, careful pre-planned process

and pop-up targets, mobile weapons that appeared on sensors only minutes before a strike aircraft was overhead; he said that the pace of decision-making around those pop-up targets, sometimes only a few minutes from first detection to weapons release, was something none of the room's more senior officers, trained in an earlier and slower generation of warfare, had ever experienced before, and that more than one of them, off the record, admitted it left them uneasy even as it proved effective, since it meant far less time existed to question a mistaken piece of intelligence before bombs were already falling.

The Double-Edged Sword: Network Warfare's Vulnerabilities

The same interconnection that gives a networked force its speed and shared awareness also creates a new and distinctive category of vulnerability, one this book will return to from a different angle in the next chapter's discussion of algorithmic decision-making. A force that depends on a continuous flow of data between sensors, headquarters, and weapons can be blinded or paralyzed not by destroying its tanks and aircraft directly, but by attacking the network that binds them together: jamming its radio and satellite links, spoofing its GPS signals, or, increasingly, penetrating its computer systems directly through cyberattack.

Russia's 2007 campaign of large-scale cyberattacks against Estonia, though aimed primarily at civilian government and banking websites rather than military targets directly, is widely regarded by military analysts as an early demonstration of the strategic potential of this kind of network attack, showing that an entire small, digitally dependent country's public institutions could be substantially disrupted without a single soldier crossing its border. In the years since, both Russia and Ukraine have made electronic warfare, jamming enemy radios, GPS signals, and drone control links, a central and continuous feature of their war, to the point that, as noted in the preceding chapter on drones, Ukrainian forces turned to physical fiber-optic cables strung out behind some of their attack drones specifically to make them immune to this kind of jamming, a striking return, in the age of artificial intelligence and satellite communication, to the same basic physical principle, a wired connection that cannot be jammed, that gave the nineteenth-century telegraph its one great advantage over early wireless radio.

A signals officer with a Western unit training Ukrainian forces observed that a paradox now defines this kind of war: the more capability a networked system offers a modern army, the more that army comes to depend on it, and the more attractive a target the network itself becomes for an adversary; he said that some of the most effective Ukrainian units they trained deliberately kept an old-fashioned analog backup plan, known map coordinates, pre-agreed radio call signs, and even runners on foot, for exactly the moment when the digital network inevitably went dark under enemy jamming, since a unit that has forgotten how to fight without its network is a unit that can be defeated simply by switching that network off.

War as a System of Systems

By the early twenty-first century, defense planners in the United States, and soon afterward in China, Russia, and other major powers, had begun describing the fully networked battlefield using a still broader term: system of systems. The idea is that a modern military no longer consists of separate branches, army, navy, air force, each fighting its own largely separate war, but of a single, deeply interconnected whole in which a satellite can cue a submarine, a submarine can cue a fighter aircraft, and a fighter aircraft can cue an artillery battery on the ground, all within the same continuous, shared operating picture, an approach the United States military now formally calls Joint All-Domain Command and Control, JADC2, and China's People's Liberation Army describes with the closely related concept of multi-domain precision warfare.

This vision brings with it a further, more subtle transformation, one that leads directly into this book's next and final technical chapter: as these networks grow larger and faster, generating and needing to process a volume of sensor data, satellite imagery, radar returns, intercepted communications, that vastly exceeds what any team of human analysts could review in real time, military planners have increasingly turned to automated and, more recently, artificial-intelligence-based systems simply to keep the network functioning at the speed its own architects designed it for. The network built to let humans see and decide faster has, in this way, begun to generate a volume and velocity of information that increasingly exceeds unaided human capacity to process, creating pressure to hand ever more of the observing, and eventually even the deciding, over to the algorithm itself, a development examined in full in the chapter that follows.

Chapter Summary

This chapter has traced the long arc from the signal fire and the trumpet call to the fully networked, system-of-systems battlefield of today. At every stage of this history, the same fundamental exchange recurs: a new technology closes the gap between what a commander knows and what is actually happening on the battlefield, and in doing so creates both a decisive new advantage and a new vulnerability, the very connection that carries orders and information can, if intercepted, jammed, or deceived, be turned against the force that depends on it. John Boyd's OODA loop and the doctrine of network-centric warfare that followed it gave this long historical pattern a formal name and a deliberate strategic purpose: victory increasingly belongs to the side that can observe, share, and decide fastest, not necessarily the side with the most powerful individual weapon.

But this same drive toward ever-faster, ever-more-integrated networks has arrived at a threshold this book must now cross explicitly. As the volume of data flowing through these networks has grown beyond what human analysts can review in the time available, military planners have turned, gradually and then with accelerating speed, to algorithms and artificial intelligence to keep pace, not merely to help a human commander see the battlefield more clearly, but, in a growing number of cases, to make the observing, the orienting, and even a share of the deciding on the network's behalf. Having examined, in this chapter, the network as a system that connects human decision-makers together, the book turns next to the question of what happens when a growing share of the decisions flowing through that network are no longer made by a human at all.

Chapter 26

Algorithms, Artificial Intelligence, and the Crisis of Decision in War

Introduction: When the Machine Decides Faster Than the Human

In all the preceding chapters, we examined weapons and systems that display the height of human capacity for destruction. But we have now reached a point where it is no longer missile power, drone accuracy, or network bandwidth, but the speed and quality of decision-making that has become the decisive factor in battle. In this age, algorithms, step-by-step sets of rules for solving a problem, and artificial intelligence, a machine's capacity to imitate human cognitive functions, have become independent actors on the battlefield.

This transformation, however, has produced a profound crisis: when a machine decides faster than a human, should the human still remain in the loop? And if the human steps out of the loop, who bears responsibility for life and death?

In this chapter, we trace the history of the algorithm's entry into the military domain, from breaking Enigma to the semi-automatic air-defense systems of the Cold War, then turn to the artificial-intelligence revolution of the 2010s and its current applications in the wars in Ukraine and Gaza. We then examine the decision crises humans have faced when confronted with algorithmic recommendations, from the downing of a Ukrainian passenger jet to the Patriot incident in Iraq in 2003. Finally, we turn to the moral puzzle of killing by machine and a future in which artificial intelligence may take a nuclear warhead into its own hands.

Part One: The Roots of the Algorithm in War: From Enigma to Early Air-Defense Systems

Code and Machine: The Birth of Algorithmic War

Although artificial intelligence is a phenomenon belonging to the twenty-first century, the algorithm, meaning an orderly method for solving a problem, has long served war. Perhaps the most prominent early example was Nazi Germany's Enigma machine and the effort of Alan Turing and his colleagues in Britain to break its code. Enigma was an electromechanical machine that encrypted German army messages using rotating rotors. Its complexity was such that the combination of possibilities reached the billions.

Turing, by designing an electromechanical machine called the Bombe and later Colossus, the world's first programmable computer, created algorithms for searching linguistic patterns amid an enormous volume of intercepted data. This effort shortened the Second World War by at least two years and saved the lives of millions. Colossus could accomplish in hours what a skilled human team would take weeks to do.

The memory of a female Colossus operator, Joanna Upton, in a 2015 interview at age ninety, recalls working in a windowless room at Bletchley Park; Colossus resembled a giant metal cabinet with blinking lights; she never forgot the clattering sound of its relays; they called it the electronic brain; each morning, they fed it paper tapes carrying intercepted messages; a quarter hour later, it would tell them what the Germans' code key was that day; none of them knew exactly how it worked; they only knew it was pulsing and telling them which German convoys were at sea; after the war, they burned everything and swore not to speak for fifty years; but honestly, she says, she never understood whether that machine thought or merely calculated; perhaps that was the difference: they could feel guilt over the bombs that took their friends' lives; it could not.

Fire-Control Systems: The First Automatic Decision Packages

After the Second World War, with the emergence of radar and aerial battles decided in a fraction of a second, armies concluded that humans were far too slow to calculate firing angles and predict a moving target's path. The result was fire-control systems, an early generation of systems that, using sensors and analog computers, automatically adjusted the angle of a gun or missile.

The most famous example was the United States Navy's Mark 1 fire-control system. This system, using radar and a mechanical analog computer, could predict an enemy aircraft's flight path and command anti-aircraft guns to fire at the point of intersection. Its next generation, in the 1950s and 1960s, employed digital computers. In effect, for the first time, a machine, not a human, decided that now is the moment to fire. Fire-control officers were mere observers who could, if necessary, press the emergency cutoff button. This model was called human-in-the-loop, a model that continues today in many semi-automatic military systems.

David's Sling and the Ballistic Goliath

The first real clash between human decision and algorithmic decision occurred in the 1980s with the deployment of the Patriot, MIM-104, defense system. Patriot, used against Iraqi short-range Scud missiles in the first Gulf War, 1991, was equipped with an algorithm that estimated the enemy missile's flight path and calculated the firing window.

The problem was that Patriot's algorithm had a cumulative timing error in its calculations, and after several days of continuous operation, it produced an error of a few seconds, which, at a Scud missile's speed, meant an error of several hundred meters. On February 25, 1991, this error caused a Patriot battery in Dhahran, Saudi Arabia, to track an incoming Scud missile but fail to calculate an intercept. The Scud struck an American military barracks, and twenty-eight soldiers were killed. Later review showed the algorithm had functioned correctly, but the operators had failed to recognize its timing drift. The company that built Patriot wrote in its report that human operators were the weak link in the system.

Part Two: The Artificial Intelligence Revolution: From Machine Learning to Autonomous Decision-Making

Until the early 2010s, military algorithms were mostly rule-based: if A occurs, do B. But advances in machine learning, and especially deep learning, in which artificial neural networks with multiple layers extract patterns from data without explicit programming, brought about a revolution in a machine's capacity to detect, predict, and decide.

Project Maven: The Pentagon's AI Eye

In 2017, the American armed forces faced an enormous volume of drone-recorded video, so much that thousands of human analysts could not review it all. The answer was Project Maven: a deep-learning-based system that could automatically detect, classify, and track people, vehicles, and military equipment in drone video. Maven, developed

in partnership with Google, could process thirty frames per second and provide human analysts a summary of important moments.

The memory of an American air force intelligence analyst, unnamed, in a 2020 interview with the New York Times, recalls that before Maven, he spent an eight-hour shift watching drone footage; desert, road, a car, the same car, a building, nothing; after Maven, the algorithm would say at second 143, an armed person exits the building; he would click and see that it really was so; the sweetest moment was when Maven showed him something he had not seen at first glance, such as a rifle poking out from behind a window; gradually he trusted it; perhaps too much; because once Maven told him a child was holding a ball in his hand; he reported it; it later turned out the ball was a piece of bread; the algorithm had erred; but in the moment, he had not doubted it; this is the most frightening part of AI in war: you learn to listen to it, even when it might be wrong.

A Turning Point: The SGS-2 Incident in Libya, March 2020

In this event, an autonomous hybrid drone built by Turkey's STM company, named Saq-2, using computer-vision algorithms, detected and, without a direct operator command, destroyed another autonomous defense system, likely a Russian Pantsir-S. The United Nations, in a report, recorded this event as the first known engagement between two fully autonomous systems, though it remains unclear whether a human was in the loop for the firing decision. But even if not, the core point stands: from that point on, war was no longer necessarily between humans.

Part Three: The Decision Crisis: Human Versus Algorithm in Fateful Moments

As machines grow faster and more autonomous, the human commander faces a dual crisis: on one hand, trusting the algorithm is often faster and more accurate than his own judgment. On the other, any algorithmic error, which often occurs unpredictably, can be catastrophic, while legal and moral responsibility rests with the human.

The Patriot Incident in Iraq, 2003: A Repeated Error

On March 22, 2003, an American ground-forces Patriot battery near the Kuwait-Iraq border destroyed a British air force Tornado GR4 fighter with two missiles. The pilot and systems officer were killed. Investigation showed that Patriot's algorithm had mistakenly classified the British aircraft as an Iraqi tactical missile. The human operator in the control room saw only an unknown mark on his screen rapidly approaching the defensive line. Following protocol, which said fire on any unknown inbound target, he pressed the button. He later said in questioning that he had not been comfortable killing a human being, but that he had trusted the algorithm; had it deceived him? No, he had been unable to distinguish a fighter from a missile; the fault was his.

The Downing of Ukrainian Passenger Flight 752, 2020: A Tragedy of Decision in a Second

On January 8, 2020, a Ukraine International Airlines passenger jet, a Boeing 737, was shot down near Tehran by an IRGC Tor-M1 air-defense system. All 176 aboard were killed. Iran's Civil Aviation Organization's final report cited human error in detection as the cause of the incident.

Technical review showed that the defense operator, under the stress caused by the possibility of an American missile attack, had identified the passenger jet as a hostile target and fired two missiles without command confirmation. The Tor system had been set to automatic mode, and its algorithm had classified the aircraft as a hostile target without issuing any warning that the target might be a passenger aircraft. The operator, trained under a doctrine of when in doubt, fire, fired.

The bitter admission of another defense operator, who asked not to be named, in an interview with a domestic media outlet, recalls that they had never been trained to target civilian aircraft; but on the night of the incident, the device told him hostile target, precisely the words he saw on the screen, hostile target; he calculated the distance to the target as thirty-six kilometers, no friend-or-foe signal was received, and the algorithm too had assessed it as hostile; who was he to argue with the algorithm; five seconds later, he fired; two days later, when he heard the news of the crash, he locked himself in his room; he still dreams every night of that green dot on the screen that vanished; he could not

believe the algorithm could be so wrong; but it had not been wrong; the algorithm had done exactly what it was programmed to do; it was he who had trusted it.

Part Four: Artificial Intelligence on Today's Front Line: Ukraine, Gaza, and War Rabbits

The War in Ukraine: A Large-Scale AI Laboratory

The Russia-Ukraine war is the first conflict in which both sides use artificial intelligence at wide scale. Ukraine, with help from Western companies, including Palantir, Microsoft, and Clearview, has deployed AI systems to analyze satellite imagery, predict the movement of Russian armored columns, and guide autonomous suicide drones. Ukrainian algorithms can, in under a minute, compare new satellite images against a library of past images and detect changes, such as newly dug trenches or missile deployments.

The memory of a Ukrainian intelligence officer, pseudonym Volodymyr, in a 2023 interview with the Washington Post, recalls having software called computer eye; you show it a point on the map and ask, was there a tank here a month ago; it immediately, after analyzing thousands of satellite images, answers, yesterday at 16:23 a T-72 tank passed through this point, heading east; they no longer look at the photos themselves; they only ask the algorithm; but once the algorithm mistakenly identified a pine tree as an armored personnel carrier; their artillery fired three rounds at that pine tree; the final decision ultimately rested with the artillery commander, but he too, like Volodymyr, had trusted the machine; since that day they set a rule: every AI output must be confirmed by two separate human analysts; it slowed them down, but it reduced needless deaths.

Gaza and the Habsora, The Gospel, Algorithm

In the Gaza war, 2023 to 2024, the Israeli army used a system called Habsora, Hebrew for the gospel or good tidings. This system, built on machine learning, can process an enormous volume of collected data, including phone calls, satellite imagery, and mobile signals, and generate, in a nearly automated fashion, a list of targets, according to the Israeli army, including Hamas members and military sites. According to numerous reports, over the course of this war the Habsora system suggested roughly thirty-seven thousand targets, many of which were struck in rapid airstrikes.

The testimony of an Israeli pilot, unnamed, in a 2024 interview with +972 Magazine, recalls that Habsora tells him, in this building is a Hamas commander, strike it; he has five seconds to decide; if he strikes, the commander's family might be down there; if he does not strike and that commander later carries out a terrorist attack, he is at fault; he asked the computer, how sure are you; it answers, ninety-two percent probability; not one hundred percent; ninety-two percent; that means one in twelve targets is wrong; he cannot identify which one; in practice, he trusted the ninety-two percent; it is the best he can do in the moment; but at night, he hears the voices of children who may have been that one-in-twelve.

Part Five: The Problem of Killing by Machine: Human Rights in the Age of the Algorithm

Up to this point, every example has shown that the final decision to fire, at least in official documents, was made by a human. But the next, and most controversial, leap is lethal autonomous weapons systems, LAWS, in which the algorithm, without human intervention, detects the target, tracks it, and, if conditions are met, destroys it. In effect, the machine acquires the right to kill.

Autonomous Anti-Radar Missiles: Ghost-Like Pioneers

The first operational examples of autonomous systems are, in fact, anti-radiation missiles such as America's AGM-88 HARM and Russia's Kh-31P. These missiles, after launch, need no human command. Their antenna tracks radar signals, and even if the enemy radar shuts off, the algorithm calculates the last recorded position and guides itself toward it. In effect, the decision to select targets and the moment of detonation is made by the missile itself.

But what has worried the international community is the next generation: intelligent turret systems with artificial intelligence, capable of distinguishing armed individuals from civilians in urban areas and firing on them without a command from above. Turkey has built a pioneering example called the Sar, or Alp 100, automatic turret system, mounted on armored vehicles, which claims to be able to identify enemy snipers amid an urban crowd.

The Campaign to Stop Killer Robots

Since 2013, the United Nations, within the framework of the Convention on Certain Conventional Weapons, CCW, has tasked a group of experts with examining LAWS. More than thirty countries, including Austria, Brazil, Pakistan, and several African countries, have so far called for a complete ban on this technology. On the other hand, the United States, Russia, China, Israel, and Britain oppose a complete ban and argue that LAWS, in conditions where communication with a commander is severed, severe electronic warfare, can enable defense and save soldiers' lives.

The account of a human-rights activist, Mona al-Sayed, from Lebanon, who works with the Campaign to Stop Killer Robots, recalls asking army officers, if a robot mistakenly kills your child, who is responsible; they fall silent; then they say, the probability of a robot's error is lower than a human pilot's; she says, but a mistaken pilot may be punished; a robot, never; in international law, the element of intent is required for a war crime; a machine has no intent; therefore whatever it does is not a war crime; they are building a generation of weapons capable of violating human rights with no legal accountability whatsoever; this is the most terrifying thing about it.

Part Six: Uranus and the Puzzle of Killing by Mistake

In defense literature, there are two types of error: type-one error, a false positive, in which a system identifies a non-threatening target as a threat and fires, the Ukrainian aircraft incident, and type-two error, a false negative, in which a system misses a real threat and fails to fire. As algorithms have advanced, type-two errors have declined, but type-one errors, owing to the complexity of deep-learning algorithms, sometimes spike unpredictably.

The Nuclear Decision Crisis and the Threshold of Automatic Firing

The oldest and most terrifying form of the decision crisis between human and algorithm lies in nuclear command-and-control systems. Since the Cold War, the superpowers have had missile-attack detection systems that are largely automated. In a crisis, a commander has only a few minutes to decide on a nuclear response. In this short window, he is in practice forced to trust the algorithm, since there is no time for independent verification. But numerous incidents have occurred in which warning algorithms erred, and only human restraint prevented catastrophe.

On November 5, 1956, several American ballistic radar stations showed a mass of targets inbound toward the East Coast. Their algorithm classified it as an imminent Soviet attack. Moments later it was determined to have been a coronal mass ejection that had disrupted radar signals.

On September 26, 1983, the Stanislav Petrov incident, the Soviet officer Stanislav Petrov, in the command bunker, received a warning of several missiles launched from American bases. The system's algorithm reported a full-scale nuclear attack underway. But Petrov, doubting the algorithm's correctness, did not initiate a counterattack. It was later determined that sunlight reflecting off clouds had deceived the satellite sensors. Petrov said years later that that night, he did not tell the algorithm you are lying; he only said wait, perhaps it is wrong; had he waited one more minute, he too might have believed it and pressed the button; all of humanity owes a debt to one moment of his personal doubt.

Part Seven: The Future: Artificial Intelligence, Autonomous Swarms, and Escalation Risk

On the horizon of the next two decades, several technological trends will sharpen the decision crisis.

First, autonomous swarms: instead of one expensive drone, thousands of small, cheap drones coordinated as a swarm. Swarm algorithms allow them, without centralized command, to divide tasks and, if necessary, decide on self-sacrifice.

Second, hyperwar, war at machine speed: in future wars with hypersonic weapons and automatic defense, the OODA loop, observe, orient, decide, act, shrinks to milliseconds. At such a timescale, a human cannot intervene. Decision-making is, in effect, handed to the algorithm.

Third, federated artificial intelligence in the command network: advanced countries are developing military neural networks in which thousands of sensors and weapons automatically coordinate with one another.

A warning from Elvis Winston, a computer scientist at Harvard University: our problem is not that machines will one day become very smart and rebel; the problem is that machines become smart enough to perform very well at specific tasks but not smart enough to understand context, intent, and probability; we build an automatic air-defense system that works correctly 99.99 percent of the time, but its 0.01 percent error is killing a passenger aircraft; now we place this system in the hands of fifty countries; the question is whether the global community is ready to accept a 0.01 percent error rate with human lives; our answer to date has been no, but every day our technology brings us closer to yes.

Summary: The Algorithm, Tool or Decision-Maker?

The algorithm and artificial intelligence in the military domain are like a fire that both gives light and burns. On one hand, automatic systems have reduced civilian casualties, through greater accuracy, saved soldiers' lives, and shortened response time against missile threats to an unimaginable degree. On the other, these same systems, when deployed without understanding human context, have led to catastrophes such as Ukrainian Flight 752.

The AI-driven decision crisis is not only a technical problem but a philosophical, legal, and moral one. As long as an algorithm, however precise, cannot distinguish intent, fear, mistake, and accident from one another, handing it the power to kill is an unacceptable risk. Perhaps the middle path is human-in-the-loop with intelligent oversight, in which the algorithm calculates and recommends every option, but the human retains veto power.

History has taught us one thing: whenever humans have built a tool that exceeds their own cognitive and physical capacities, from the stone axe to the nuclear bomb, it has always taken time for norms of control and accountability to form around that tool. Military artificial intelligence is no exception to this rule. The question is whether we will reach a global agreement to contain killer robots before an irreversible catastrophe occurs, or whether, as with nuclear weapons, we must first witness a catastrophe before we awaken. The answer to this question must be given not by artificial intelligence, but by humans themselves, though this time, time may no longer be on our side.

Chapter 27

Humanity, Creativity, and Responsibility in the Age of Ultimate Tools

At the End of the Journey, a Return to the Beginning

Over the past twenty-seven chapters, we have traveled a path that began with the first stone axe and wooden spear, passed through the iron sword and the composite bow, arrived at gunpowder and artillery, crossed through armored battleships and jet aircraft, stepped into the nuclear age and the most horrifying weapons of mass destruction, reached the height of speed and precision in autonomous drones and hypersonic missiles, and finally, in command networks and artificial-intelligence algorithms, arrived at a threshold where the machine decides faster than the human. But at the end of this journey, perhaps the most important question remains unanswered: what place does the human being hold amid all these ultimate tools?

This chapter is an answer to that question. Here, we will speak of the collective wisdom of commanders and philosophers, of the courage and sometimes folly of leaders, of the remorse of scientists who served hell, and of the hope of mothers who raise their children for peace. War, before it is a battle of iron and fire, has always been a test for humanity, a test of intelligence, of courage, of the capacity for empathy, and of the ability to restrain destructive instincts. The age of ultimate tools has made this test harder than ever before, but not so hard that humanity cannot emerge from it with its head held high.

Part One: Military Creativity: Why Is the Human Still Superior to the Machine?

In all the preceding chapters, we emphasized the machine's speed, accuracy, and data processing. But in one domain, even the most advanced algorithms have not been able to surpass the human: creativity, the ability to break frameworks, to invent strategies recorded in no textbook, and to use an enemy's mistakes as opportunity. An algorithm can find the best path within a previously foreseen situation, but it cannot imagine a scenario that has never occurred.

A human can.

Guerrilla War in the Age of the Drone

In the 2010s, while modern armies were investing billions of dollars in C4ISR systems, insurgent groups in Syria and Iraq showed astonishing creativity using commercial DJI drones and homemade bombs. One ISIS commander, later detained, said in questioning that they had had no budget, only YouTube and ingenuity; their engineers had built a remote-control system from PlayStation console parts; the day after one of their drones was destroyed, an American leader said on television that they were ignorant savages; the next day, with two drones fitted with anti-tank grenades, they struck two of the enemy's Humvees; creativity cannot be bought with a budget.

General Soleimani and Asymmetric Warfare

In contemporary Iranian history, few commanders are as renowned as General Qasem Soleimani for the use of tactical and strategic creativity to offset an enemy's technical superiority. Understanding that the region's conventional armies lacked Iran's access to equipment and command networks, he designed what might be called advanced proxy warfare: training, equipping, and coordinating resistance groups with decentralized, hybrid strategies. An Iraqi military analyst, describing his method, said that Soleimani was like a chess player whose pieces were the cheapest on the board, but who knew exactly which piece to place on which square to checkmate his opponent's king in three moves; no algorithm could have predicted this, because he himself had written the rules of the game.

Emotional Intelligence on the Battlefield

One of the human's fundamental advantages over the algorithm is the capacity to understand emotions, fear, anger, pride, despair, in oneself and in the enemy. In the battles in Gaza, Israeli commanders used teams of psychologists and negotiators, not merely predictive algorithms, to estimate the likelihood of civilians leaving a besieged area. On the other side, Hamas commanders, aware of Israeli society's fear of hostage-taking, designed their tactics to create psychological pressure.

The memory of a retired Indian colonel, pseudonym Suri, in a 2021 interview, recalls that at five thousand meters altitude, drones and radar often fail; there, it is a soldier's eyes and judgment that determine whether an enemy movement is provocation or an ordinary mistake; once a Chinese soldier slipped near the border and crossed into their territory, his rifle falling to the ground; his own soldier could have targeted him; he said over the radio from the command room, Nur, don't fire; if it was an accident, help him up; that single human decision prevented a major clash; no algorithm can tell whether a fall is an attack or carelessness.

The Dark Sides of Creativity: From Hiroshima to Standoff Weapons

Military creativity has not always served the good. Many technical innovations we call progress today were once known as hellish magic. The creators of these tools were sometimes filled with pride, and sometimes filled with remorse.

Oppenheimer and Awareness After Trinity

The story of Robert Oppenheimer, father of the atomic bomb, is perhaps the most famous account of poisoned creativity in the modern age. He and his team at Los Alamos, with scientific zeal and mad ambition, solved the equation of nuclear weaponry. When the first nuclear explosion, Trinity, occurred on July 16, 1945, Oppenheimer murmured the famous line, now I am become death, the destroyer of worlds, from the Hindu text the Bhagavad Gita. But years later, when asked whether he felt responsible as a scientist, he answered that they had done this deed, and

that its responsibility would never be lifted from their shoulders; scientists have known sin, and this is a knowledge they cannot lose. Oppenheimer spent his final years fighting against the building of the hydrogen bomb and was ultimately, at the height of his disillusionment, removed from his post.

The Nazi Engineer and Rockets That Did Not Save

On the other side, Wernher von Braun, chief designer of the V-2 rocket, was brought to America after the war and later designed the Saturn V rocket that carried humans to the moon. But he could never be absolved of the crimes of the Mittelwerk camp, where thousands of prisoners lost their lives on the V-2 production line. Von Braun said in a postwar tribunal that his goal had been to build a rocket for travel to space, but that the paths to reaching one's dreams sometimes pass through hell.

The Problem of Moral Distance

Modern technology has increased the physical distance between killer and victim to an unprecedented degree. In early wars, you had to drive your sword into an enemy's chest and see his face. Today, a drone operator can sit in Nevada and, with a joystick, drop a bomb on a family in Yemen. This distance, which psychologists call moral distance, weakens empathy.

The account of a retired American drone operator, unnamed, in a 2021 interview, recalls that the hardest day he had was not the day his target was a Taliban commander; the hardest day was when he saw a child selling sweets run toward a car carrying a bomb; he knew the bomb would explode within thirty seconds and kill him; he could destroy the car with a Hellfire missile before the explosion, but the child would also die in that blast; the algorithm told him, do not strike, wait; but his heart told him, strike, prevent the greater death; he did not strike; the child died in the larger explosion; responsibility for that decision was his alone; the algorithm bore no responsibility; the next night, he resigned.

Law, Ethics, and Responsibility on the Battlefield

With the rise of autonomous weapons and decision-making algorithms, the question of criminal responsibility has entered a gray zone. If an autonomous drone bombs a school, who is at fault? The programmer who wrote the algorithm? The commander who deployed the drone? The operator who pressed the automatic-execution button? Or the algorithm itself?

Foundational Principles of the Law of War

The foundation of international humanitarian law rests on three principles: distinction, between combatant and civilian, proportionality, harm to civilians must not exceed the military advantage of an attack, and precaution, all possible measures to reduce collateral harm. These principles were written for humans, not machines. An algorithm can perform distinction relatively well, but proportionality and precaution require value judgment.

Trial of the Algorithm: Germany, 2022

In December 2022, a German military tribunal, for the first time in history, reviewed a case in which an intelligent decision-support system had mistakenly classified a civilian Afghan vehicle as a vehicle carrying explosives, and the aircraft's pilot, based on that recommendation, had destroyed the vehicle. The court ultimately acquitted the pilot but ordered the system's manufacturer to pay compensation to the victim's family owing to a lack of algorithmic transparency. The judge wrote in the ruling that when an intelligent system recommends something to a human and the human, owing to natural trust in the system, refrains from independent verification, responsibility is divided between human and system; since the system bears no legal responsibility, civil liability falls to its manufacturer.

The Just Following Orders Syndrome Versus Individual Conscience

In the age of artificial intelligence, the defense the algorithm told me so, and I had to trust my electronic colleague is a new form of the just following orders defense. Courts still lack clarity in confronting this defense.

The memory of an Italian soldier present at the Battle of Nasiriyah, 2003, recalls that at a checkpoint, the automatic identification system warned them that an approaching civilian vehicle had been classified as a threat; their commander, Captain Bueno, ordered the vehicle to stop, but the system automatically locked the machine gun onto the vehicle; he was at the gunner's position; the commander said, I give the order to fire; but the system had sent a recommend firing signal; he looked into the commander's eyes and said, the system is wrong, there's a woman behind the wheel; the commander paused a moment and pressed manual review; the vehicle passed; two days later, it turned out the vehicle had not been carrying explosives; the commander told him, Nicky, you saved your own life; he said, no, it was you who did not listen to the algorithm.

A Vision of Peace: Can Humanity Prevent Its Own Extinction?

With the accumulation of so many lethal tools, what does the prospect of disarmament and lasting peace look like? The bitter reality is that none of the weapons introduced in this book have been permanently rendered obsolete. Chemical and biological weapons, despite prohibition conventions, still exist in the secret stockpiles of some countries. Nuclear weapons have not only failed to become obsolete but have grown more dangerous with new technologies. Autonomous drones and artificial intelligence have also joined this list.

From Realism to Idealism: The Eternal Cycle

Two classical perspectives exist on war and peace: realism, which holds that humans are inherently warlike and that only deterrence and balance of power can prevent major conflict, and idealism, which holds that by strengthening international institutions, shared trade, and peace education, the root of war can be dried up. History has shown that the truth lies between these two: the balance of terror has, to date, prevented nuclear war, but has failed to prevent limited, proxy, and civil wars.

A Collective Word from Scientists for the Future

In 2015, a group of physicists, biologists, and artificial-intelligence specialists, including Stephen Hawking and Elon Musk, published a statement calling for a global ban on lethal autonomous weapons systems, LAWS. They warned that an arms race in this domain could lead to a third revolution in the method of warfare, after gunpowder and the nuclear bomb, one that would erase moral red lines entirely.

Stuart Russell, in a 2020 World Economic Forum address, said that we imagine the issue of autonomous weapons to be a far-off matter, but that they are already present on the battlefields of Yemen, Libya, Ukraine, and Gaza; their difference from old cruise missiles lies only in the power of choice; an old cruise missile can never, for the rest of its existence, decide to go to a different target instead of its assigned one; an autonomous missile can; and this choice, however limited by algorithm, gives it agency; should we give a machine such agency or not? He says: never.

The Human, Center of the Circle of Decision

After twenty-eight chapters, we arrive at a simple but profound truth: no tool, however intelligent and autonomous, can lift the moral responsibility of the final decision over life and death from human shoulders. It is the human who can move faster than the algorithm and show mercy to an innocent child on the verge of an explosion. It is the human who can resist the allure of nuclear deterrence and choose the path of negotiation. It is the human who, after seeing the images of Hiroshima, can challenge the very structure of weapons of mass destruction. And it is the human who, in the end, if he errs, whether an emperor or a defense operator, must answer to his own conscience and to history.

A Brief Word to the Book's Readers

This book has been a journey through the darkest and brightest technical achievements of humankind. From the wooden spear to artificial intelligence, we have advanced the art of killing one another to an extraordinary degree. But the hope is that, by seeing this path of evolution, we might also manage its reverse course: the gradual reduction of

violence, the restriction of inhumane weapons, and the expansion of a dialogue in which, instead of missiles, words are exchanged.

A Final Memory: A Snowball in the Truce

In December 1914, on the first Christmas of the First World War, British and German soldiers spontaneously declared a truce. They came out of their trenches, sang songs to one another, and even arranged a game of football. The German soldier Kurt Siemens later wrote that that morning, an Englishman had given him chocolate; that afternoon, their commander ordered them to fire on those same trenches; he could not, not out of fear, since his machine gun had long range, but simply because he did not want to fire on someone who had shaken his hand an hour before; when the firing began, he aimed his shots above their heads; three days later, he was summoned before a military tribunal for insubordination; he told the judge, I am a human being, not an algorithm; the judge did not know what an algorithm was; neither did he; but today, he wishes the war computers of our age carried such a human being within them too.

These brief words from the German soldier may be the best summary of all the preceding chapters: before we are soldiers, scientists, engineers, or algorithms, we are human beings. And at the center of the circle of decision, the human, with all his flaws, shortcomings, and inherent good and bad, will always remain the fixed point.

Special Feature

Directed-Energy Weapons (Solid-State Lasers)

Firing at the Speed of Light, the Cost of a Cup of Coffee

Among all the military technologies humanity has built to date, perhaps none has come as close to the boundary of science-fiction magic as directed-energy weapons, DEW. Lasers, particle beams, and microwave weapons, seen only in Star Wars films until just two decades ago, are today quietly moving out of laboratories and onto real battlefields.

Among the various types of directed-energy weapons, solid-state lasers have drawn the most attention from the world's armies owing to their balance of size, power consumption, cost, and efficiency. Rather than a physical projectile, these weapons use a focused beam of light to melt, pierce, or blind a target. Their most important advantage, one that permanently changes the economic equation of war, is that each shot costs only a few dollars in electricity, compared to defensive missiles that cost hundreds of thousands of dollars each. In this survey, alongside explaining the physical foundations of solid-state lasers, we trace their historical evolution from early laboratories to today's battlefields.

Part One: Technical Foundations and the Physics of Solid-State Lasers

What Is a Laser and How Does It Work?

Laser is an acronym for light amplification by stimulated emission of radiation. Unlike ordinary light, such as sunlight or lamp light, which is composed of waves with differing phases and wavelengths, laser light is coherent, meaning all photons move in a single phase, a single direction, and a single wavelength. This property allows laser light to concentrate its energy on a very small point and generate tremendous heat, enough to melt metal.

A military laser consists of four main components. First, the gain medium, the material within which light is amplified. In solid-state lasers, this medium is a solid crystal or glass, such as Nd:YAG, neodymium-doped yttrium aluminum garnet, doped with rare-earth metal ions, neodymium, ytterbium, erbium, and others.

Second, the pump source, the energy that excites the gain medium's electrons to a higher level. In modern lasers, this is done by semiconductor laser diodes. The diode-pumping method has raised the efficiency of converting electrical to optical energy from a few percent to beyond thirty percent.

Third, the optical cavity, two mirrors on either side of the gain medium that reflect light back and forth between them. One mirror is fully reflective and the other partially reflective, so that part of the light exits as the laser beam.

Fourth, the cooling system: even at thirty percent efficiency, seventy percent of input energy converts to heat, which can melt the laser crystal. For this reason, complex cooling systems, liquid-based, refrigeration-cycle, or thermal pumps, are the heart of every high-power military laser.

The Core Challenge: Thermal Management and Beam Combining

The greatest obstacle to building high-power military lasers is thermal management. The higher a laser's power, the more heat it generates, and without proper cooling, the laser crystal is destroyed within a fraction of a second. Engineers use several methods to solve this problem: crystals with a low thermal-expansion coefficient, such as YAG, thin-disk laser designs, in which heat is dissipated from behind the disk, and high-speed liquid-flow cooling systems.

The second challenge is beam combining. A single laser module, owing to thermal limitations, cannot exceed a certain power, say fifty kilowatts. To reach powers of one hundred, three hundred, or even one thousand kilowatts, the beams of several lasers must be combined. Three main methods exist: coherent combining, the most complex and precise, spectral combining, more practical, and incoherent combining, the simplest method, seen in some laser systems, though it reduces beam quality.

Part Two: History: From Laboratory to Battlefield

The 1960s to 1980s: Great Dreams and Great Failures

The world's first laser was built in 1960 by Theodore Maiman at Hughes Research Laboratories, a ruby laser with a power of a few milliwatts. The American military immediately grasped its military potential and launched numerous projects to build a laser gun. But for two decades, no practical success was achieved. The lasers of that era were so inefficient that melting a piece of metal required power equivalent to an entire power plant, and their cooling systems were the size of a large room.

In the 1980s, Ronald Reagan launched the Strategic Defense Initiative, SDI, Star Wars program to counter Soviet ballistic missiles using space-based, chemical-type, lasers. The chemical oxygen-iodine laser, COIL, reached megawatt power in this project, but its inherent bulk, physical size, and need for toxic chemicals made it impractical. Ultimately, with the Soviet collapse, SDI was cancelled, but the technical groundwork for the next generation was laid.

The 1990s to 2010s: The Diode-Pumping Revolution

The 1990s marked a turning point in solid-state laser development: the emergence of high-power laser diodes and the diode-pumping method raised efficiency from a few percent to beyond thirty percent and sharply reduced system volume and weight. In the early 2000s, the Joint High Power Solid State Laser, JHPSSL, program at American laboratories achieved one hundred kilowatts in continuous-wave mode at White Sands Missile Range, the beginning of a new era for military lasers.

In 2014, the United States Navy's first operational laser, the Laser Weapon System, LaWS, with a power of roughly thirty-three kilowatts, was installed aboard the USS Ponce and deployed in the Persian Gulf. This laser used visible light and could blind drone sensors, set small boats ablaze, and, at low power, illuminate a target for identification. The cost per LaWS shot was only fifty-nine cents.

Today: From HELIOS to Iron Beam

From 2020 onward, solid-state lasers have entered a stage of operational maturity. Lockheed Martin's HELIOS system, with a power of sixty to 150 kilowatts, is installed on Arleigh Burke-class destroyers and coordinates with the Aegis combat system. Raytheon's DE M-SHORAD system, with fifty kilowatts, is mounted on the Stryker armored vehicle to counter rockets, artillery, mortars, and drones. And most importantly, Israel's Iron Beam system, with 100 to 150 kilowatts, has been deployed at the Gaza border and can intercept rockets and mortars at a cost of only two dollars per shot, compared to fifty thousand dollars for each Iron Dome Tamir missile.

The World's Solid-State Laser Arsenal: A Comparative Analysis

The United States: The Undisputed Leader

America is without doubt at the forefront of military laser development. Its most important programs include:

HELIOS, High Energy Laser with Integrated Optical-dazzler and Surveillance: a sixty-to-150-kilowatt system installed on Arleigh Burke-class destroyers, such as the USS Preble. It can coordinate with the Aegis fire-control system and target drones, fast boats, and even cruise missiles.

DE M-SHORAD, Directed Energy Maneuver Short-Range Air Defense: a fifty-kilowatt laser on the Stryker armored vehicle, designed to counter rockets, artillery, mortars, and drones. The first units of this system were delivered to the American army in the fall of 2024.

IFPC-HEL, 300kW, Valkyrie: Lockheed Martin's three-hundred-kilowatt program, intended for truck mounting with the capability to intercept cruise missiles and larger rockets. But in March 2026, the American army removed this program from official-program status owing to technical problems, thermal management and large system size, reducing it to a research prototype.

HELCAP, High Energy Laser Counter-ASCM Program: the United States Navy's three-hundred-to-five-hundred-kilowatt program to counter anti-ship cruise missiles. This program remains under development and is expected to reach fruition by the late 2020s.

ODIN, AN/SEQ-4: a low-power, ten-to-thirty-kilowatt optical dazzler system that disables drones' optical sensors. It has been installed on eight Arleigh Burke-class destroyers since 2020.

Russia: From Peresvet to Zadira

Russia's military laser program has always been accompanied by propagandistic exaggeration, but it also has real achievements.

Peresvet: Russia's first and primary operational laser, unveiled by Putin in 2018 and formally entering service in 2019. Peresvet is a dazzler laser, not a physically destructive one. Its main task is blinding enemy reconnaissance satellites in low Earth orbit, LEO, and protecting missile sites. It is truck-mounted, and its effective range against satellites is estimated at roughly five hundred to eight hundred kilometers.

Zadira: Russia's new generation of destructive lasers, unveiled in December 2024. Its power is estimated between fifty and one hundred kilowatts, and according to Russian reports, it can destroy a drone at a distance of five kilometers within five seconds, and its beam melts satellite optics within a fraction of a second. Zadira is built on solid-state fiber lasers and is more advanced than Peresvet.

China: The Silent Hunter and Competitive Power

China is approaching the United States in military lasers at a remarkable pace and, in some areas, such as patent numbers and space tests, has even taken the lead.

The LW-30 system: a thirty-kilowatt fiber-laser-based system displayed at the Zhuhai military exhibitions. Its effective range against drones is stated as roughly four kilometers.

Silent Hunter: a thirty-to-fifty-kilowatt system China has exported to Saudi Arabia. Its peak success was recorded in 2022: in one day, it downed thirteen Houthi suicide drones. Even so, Saudi officers have complained of its performance in intense heat and desert dust; in some cases, fifteen to thirty minutes of continuous targeting was needed to ensure a target's destruction.

Power at one hundred kilowatts and beyond: the Chinese company Raycus produces three-hundred-kilowatt fiber-laser modules. China is also developing the Shengguang, divine light, project to achieve megawatt-class lasers for military and nuclear-fusion purposes.

Iran: Domestic Steps in the Shadow of Sanctions

Despite extensive sanctions, the Islamic Republic of Iran has taken notable steps in high-power laser technology and is today one of the few countries in the region to have achieved operational laser systems.

The Seraj precision laser system: Iran's first domestic precision laser system, unveiled in January 2025. This system is mounted on a multi-purpose military vehicle and has been deployed around the Fordow nuclear facility. Its official mission is stated as protecting sensitive airborne assets and nuclear centers against enemy reconnaissance and offensive drone attacks. Seraj's output power is estimated between ten and thirty kilowatts, and it uses beam-steering technology for precise beam guidance.

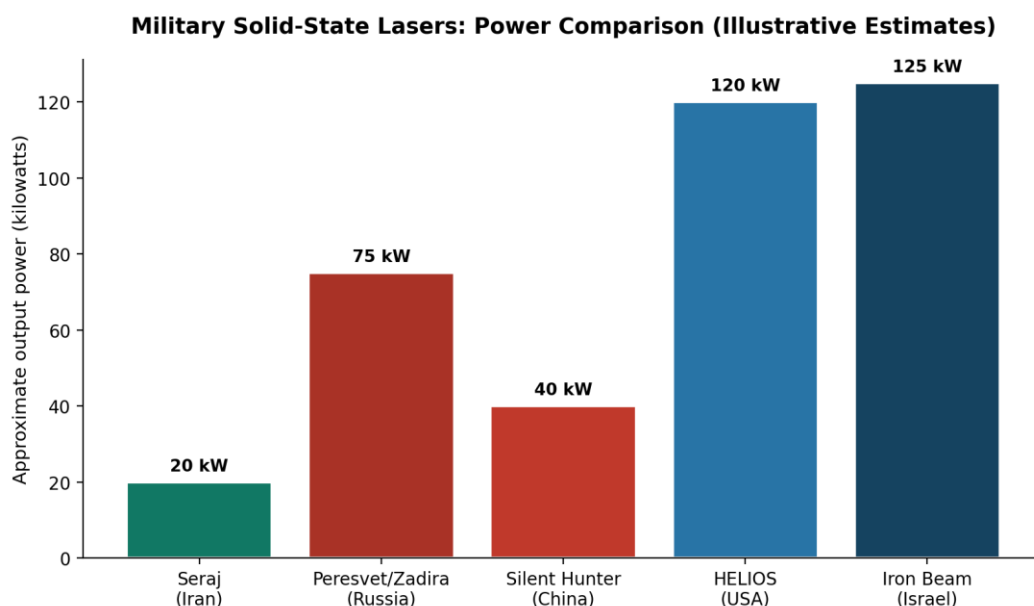


Chart: Approximate output power of selected military solid-state laser systems (author's diagram, illustrative open-source estimates).

The Sayyad laser defense system: a system displayed in IRGC exercises, mountable on tactical vehicles and trucks. Its notable feature is a high rate of fire and the capability to engage several sequential targets at distances beyond five kilometers.

Development of laser-guided bombs and missiles: beyond defensive systems, Iran has also unveiled the Basir laser-guided bomb. This bomb can, using ground or airborne laser designation, strike targets with high accuracy at a distance of up to forty kilometers.

Challenges and outlook: Iran has not yet achieved 100-to-300-kilowatt laser technology capable of intercepting ballistic and cruise missiles. Even so, relying on domestic capability and reverse engineering of foreign examples, including acquired laser systems, it is progressing at a relatively good pace. Western analysts believe Iran could achieve hundred-kilowatt lasers within the next five to ten years.

Israel: Iron Beam, Which Changed the Equation

Israel has brought about a fundamental transformation in short-range defense with its Iron Beam system. This 100-to-150-kilowatt system, built by Rafael, was operationally deployed at the Gaza Strip border in December 2024. Its main advantage, beyond destructive power, is a cost of only two dollars per shot, compared to fifty thousand to one hundred thousand dollars for Iron Dome missiles. Iron Beam can intercept rockets, mortars, drones, and even short-range

missiles at a distance of up to seven kilometers. In 2025, a hacking group published confidential documents from this system showing that Israel is developing a three-hundred-kilowatt version of it for intercepting cruise missiles.

Applications and Operational Limitations

Main Applications of Solid-State Lasers

First, countering drones and loitering munitions, C-UAS: this is the most attractive and operationally mature application of military lasers. A fifty-kilowatt laser can, with a few seconds of continuous irradiation, melt a drone's plastic or carbon-fiber shell and disable its electronic systems. The low cost per shot, a few dollars against tens of thousands of dollars for a missile, has made the laser an ideal tool for countering swarms of cheap drones.

Second, short-range point defense, SHORAD, against rockets, artillery, and mortars, C-RAM: systems such as Israel's Iron Beam have shown that 100-to-150-kilowatt lasers can intercept and destroy short-range rockets and mortars at a distance of a few kilometers. The main challenge in this domain is dwell time; rockets are far faster than drones and provide less opportunity for laser irradiation.

Third, dazzling sensors and satellites: low-power lasers, ten to thirty kilowatts, can blind the optical sensors of drones, aircraft, and satellites. This application is banned under the United Nations Protocol on Blinding Laser Weapons, 1995, but countries continue to use dazzling lasers for temporary vision disruption, without permanent blinding.

Fourth, intercepting cruise and ballistic missiles, an unrealized ambition: this is the highest level of military laser application and requires power from three hundred kilowatts to a megawatt. Ballistic missiles, at speeds of five to twenty-five Mach and with multi-layer thermal insulation, present a major challenge for lasers. Programs such as America's HELCAP and Israel's Golden Dome are focused on this capability, but no country has yet reached the operational stage in this domain.

Limitations and Weaknesses

Despite remarkable advances, solid-state lasers still face serious limitations.

Atmospheric effects: rain, fog, dust, smoke, and even thermal blooming of the air scatter and absorb the laser beam. Tests have shown that in rainy weather, a laser's effective range drops by up to sixty-seven percent, from ten kilometers to three kilometers. In the deserts of Saudi Arabia, China's Silent Hunter system has had serious problems with dust.

Thermal management and system size: the power generator, a giant generator, heavy cooling system, and large battery stores are the biggest obstacles to deploying high-power lasers on light armored vehicles or tactical aircraft. America's IFPC-HEL system was, in part, removed from its program for exactly these reasons.

Dwell time: to melt metal and penetrate a target's body, a laser must remain focused, continuously and without shaking, on a specific point for several seconds. Against fast-moving targets, such as a cruise missile or a fighter aircraft, this is very difficult.

Countermeasures: an enemy can install reflective surfaces, mirror coating, or heat-resistant ceramic coatings on drones. Also, launching hot flares and thick smoke reduces the laser beam's absorption rate.

Relationship with High-Power Microwaves, HPM: A Complementary Piece of the Puzzle

Military analysts often regard solid-state lasers and high-power microwaves, HPM, as complementary to one another. While a laser is a narrow, precise beam that can melt a specific drone at a point, high-power microwaves produce broadband waves, similar to a small electromagnetic bomb, that can burn out the entire electronic circuitry of a full drone swarm in an instant, without physically destroying the body.

The most prominent operational project in this domain is America's Epirus Leonidas system. Leonidas, using AESA phased-array antennas instead of a traditional dish, can focus a microwave beam and fit within a truck. In one test,

this system, with a single pulse, halted forty-nine swarming drones simultaneously in just two seconds, an unprecedented record. China has also built a similar system called Hurricane-3000.

The future of short-range air defense is moving toward combined platforms, laser plus HPM: microwave for cheap drone swarms, laser for point and harder targets.

Future Outlook: Airborne, Space-Based, and Megawatt Lasers

Airborne Lasers

Efforts to mount lasers on aircraft date back to the 1980s but have always ended in failure. The American air force's SHIELD, Self-protect High Energy Laser Demonstrator, program to mount a fifty-to-one-hundred-kilowatt laser on fighters, to blind enemy missiles, was halted owing to weight and cooling problems. Even so, China claimed in 2024 to have successfully tested a hundred-kilowatt laser aboard a large aircraft, the Y-20. Airborne air-defense lasers are expected to become operational on transport aircraft and bombers by the early 2030s.

Space-Based Lasers

The idea of deploying lasers on satellites to intercept ballistic missiles in the boost phase is the oldest dream of Star Wars. Both China and Russia have secret programs in this domain, and the United States is also pursuing the Golden Dome program, with a budget of 175 billion dollars, to deploy a layer of space-based interceptors, including lasers and railguns. But enormous technical obstacles, power, cooling, launch cost, remain unsolved, and many analysts consider these programs impractical.

Megawatt Lasers and Ballistic-Missile Interception

Reaching megawatt power for intercepting intercontinental ballistic missiles still appears distant. The greatest challenge is not power generation but keeping the beam focused across a distance of hundreds of kilometers and through turbulent layers of the atmosphere. Even so, research programs in the United States, China, and Russia continue, and the first operational megawatt laser systems are projected for around 2040, if it is possible at all.

A Revolution That Has Just Begun

Solid-state lasers have today moved from a science-fiction idea to a real, influential weapon on the battlefield. Systems such as LaWS, HELIOS, and Iron Beam are now deployed in the Persian Gulf and at the Gaza border, destroying enemy drones and rockets at a cost of only a few dollars per shot. This shift in war's economic equation may be more important than any other technical advance: in a war where cheap drones can saturate million-dollar defense systems, the only weapon that can counter them at similarly low cost is the laser.

Even so, a long road remains before a laser rifle is in the hands of every soldier. Weight, volume, thermal management, and dependence on weather conditions are obstacles that may take decades to solve. But the direction is clear: the future of air defense, the future of drone warfare, and perhaps even the future of missile defense, is moving toward directed-energy weapons. Whatever country can bring portable three-hundred-kilowatt lasers to mass production will shift the equation of air power in its favor for decades to come.

Meanwhile, Iran, despite sanctions, has taken its first steps and operationalized the Seraj system. The gap with leading powers remains notable, the United States and Israel have reached 150-kilowatt lasers and China is at the threshold of three hundred kilowatts, while Iran remains in the ten-to-thirty-kilowatt range. But the pace of progress suggests that, if the current trend continues, Iran could join the hundred-kilowatt laser club within a decade. At that point, the Persian Gulf and western borders will witness a new generation of battles, battles in which, instead of a hail of missiles, invisible beams of light move through the sky and decide the fate of war in a fraction of a second.

Special Feature

New Weapons: Flamethrowers, Electric Guns, and Plasma Weapons

Three Different Frontiers of Military Innovation

Among the mass of advanced weapons examined in this book, from hypersonic missiles to autonomous drones and solid-state lasers, three categories of weaponry, though classified as new, have followed very different evolutionary paths. The flamethrower is rooted in humanity's most ancient fear of fire and has today been transformed into rocket and thermobaric configurations. The electric gun has crossed the line between weapon and restraint tool and created a legal and moral puzzle. And plasma weapons still reside mostly in the realm of science fiction, so entangled between reality and fantasy that the boundary itself has become a subject of theorizing. In this survey, we examine all three categories from historical, technical, operational, and forward-looking perspectives.

The Flamethrower: From Greek Fire to Thermobaric Munitions

Greek Fire: A 1,400-Year-Old Ancestor

Before speaking of modern flamethrowers, we must mention Greek fire, a weapon invented in the seventh century CE by the Byzantine Empire, which can, in many respects, be called history's first flamethrower. The Byzantines poured a mixture of naphtha, sulfur, and quicklime into bronze tubes and, by pressing a piston, created a fountain of fire that burned even on water. This weapon shattered the Arab fleet at the siege of Constantinople in 678 CE, and its formula remained a Byzantine monopoly for centuries. Greek fire's exact formula is lost today, but this historical reference alone testifies that the fountain of fire was among the earliest human tools for combining chemistry, fear, and tactics on the battlefield.

The Birth of the Modern Flamethrower: From the Flammenwerfer to the Second World War

The flamethrower did not take its modern form until the early twentieth century. In 1901, the German inventor Richard Fiedler built the first operational Flammenwerfer. This weapon's mechanism worked as follows: inert gas pressure, usually nitrogen, propelled a stream of liquid fuel, heated petroleum or diesel, out through a nozzle, and after passing an electric igniter, the mixture caught fire. German combat engineers used this weapon against French trenches at the Battle of Verdun, 1916. The image of a twenty-meter jet of fire blowing through a narrow trench and turning all its occupants to ash within a fraction of a second had such a psychological effect that British reports called it hell in a tube.

By the end of the First World War, flamethrowers were used extensively on both fronts, but their inherent flaws also became apparent. The effective range of these weapons was only twenty to forty meters. The weight of the fuel tank, usually more than thirty kilograms, sharply limited a soldier's mobility. Most important was the operator's catastrophic vulnerability: if a bullet struck the fuel tank, the soldier effectively became a moving torch. This very vulnerability made the flamethrower a near-suicidal weapon, carrying it required great courage, or perhaps madness.

The Second World War witnessed the classic peak of backpack flamethrowers. German models such as the Flammenwerfer 35 and 41 and American models such as the M1 and M2 were used in clearing trenches and machine-gun positions. In the war's final scenes in the Pacific, American Marines at Iwo Jima and Okinawa used flamethrowers to drive Japanese soldiers out of underground tunnel networks, a space where every other weapon was ineffective.

Legal Limitations and the Decline of Backpack Flamethrowers

Protocol III of the United Nations Convention on Certain Conventional Weapons, 1980, sharply restricted the use of incendiary weapons against civilians. Although use against military targets remained permitted, it was difficult to erase the flamethrower's inhumane image. The armed forces of many countries, including the United States, gradually retired backpack flamethrowers from the late 1970s onward. Even so, the idea of the fountain of fire was not entirely abandoned; it was recreated in new, more complex forms.

A New Transformation: Rocket Flamethrowers and Thermobaric Munitions

A soldier on today's battlefield rarely moves with a fuel pack on his back. Instead, the modern flamethrower has been recreated in the form of thermobaric rockets. These weapons, sometimes also called vacuum weapons, first disperse a cloud of powdered or gaseous fuel into the environment and then detonate it. The result is a two-stage explosion: first, an initial pressure wave that crushes buildings, and then a widespread fire that consumes the oxygen present in the space and creates a relative vacuum, hence the nickname vacuum weapon. The temperature at the center of a thermobaric explosion reaches beyond three thousand degrees Celsius, and organic tissue, including the human body, effectively vaporizes.

The prominent symbol of this generation is Russia's TOS-1 system. The TOS, mounted on a T-72 tank chassis, has twenty-four 220-millimeter thermobaric rocket launch tubes. In a single mass launch, this system covers an area four hundred by four hundred meters with a cloud of fire and an extraordinary pressure wave. The TOS's effective range is between six and twelve kilometers. The improved TOS-1A version, with a more advanced fire-control system, and the newest version, the TOS-3 Dragon, unveiled in 2024, are also equipped with anti-drone protective cages and an active protection system. Russia's use of the TOS-1A against fortified Ukrainian positions in the war in Ukraine has been widely reported.

On the other side, China too, in January 2025, released footage of its soldiers training with a new backpack flamethrower. In this footage, a stream of fire was fired at simulated targets at an estimated distance of sixty to eighty meters. Some media outlets claimed this weapon could melt human flesh. Although this description is more journalistic than technical, it shows a relative return to the idea of a direct fire fountain, with better fuel and pumping technology, alongside thermobaric rocket launchers.

From Legend to Reality: The Story of the Hellfire Torch in Iran

Among the news and rumors in the field of thermal weapons, a report sometimes appears so astonishing and unverified that its credibility is difficult to establish. One of the most prominent examples is the story of the Hellfire Torch, a weapon that, according to some unconfirmed accounts, Iran's IRGC intended to build and had even unveiled in the Fuman region. According to some media reports, this giant weapon, described as a new thermal rocket launcher, was intended, with high thermal power, to destroy enemy trenches and fortifications in offensive operations. But a year after this news, the IRGC commander in Fuman announced that this weapon had been shelved owing to technical problems and had, in practice, never entered operational service. This affair is an interesting example of the gap between claim and operational reality in the defense industry. While no independent, credible source confirms the existence of such a weapon, the story of the Hellfire Torch has become one of the legends circulating online about Iranian weapons.

The Electric Gun, or Taser: Controlled Shock at the Border of Life and Death

If the flamethrower symbolizes violent annihilation of a target, the taser, whose brand name is applied to an entire category of electroshock weapons, symbolizes restraint, a weapon designed for temporary paralysis and incapacitation, not killing. This fundamental difference sets the taser apart from every other weapon in this survey.

Definition and Technical Function

The taser, an acronym for Thomas A. Swift's Electric Rifle, taking its name from a Tom Swift science-fiction novel, is a high-voltage, roughly fifty thousand volts, very-low-current, under three milliamperes, electric device. Its operating mechanism works as follows: firing two copper prongs through thin wires into the target's body forms a closed loop. The resulting current causes involuntary muscle contraction and temporary disruption of the nervous system. Electrical pulses at a frequency of nineteen per second deceive the body's autonomic nervous system and effectively immobilize the victim for a few seconds to a minute.

A taser's internal components include an ordinary battery, nine volts in older models, rechargeable lithium in newer ones, a flyback converter circuit that raises the battery's low voltage to beyond fifty thousand volts, energy-storage capacitors, and a firing tube containing compressed gas, CO₂. Two prongs, with thin wires up to ten meters long, are launched by the compressed gas and, after penetrating the target's clothing, even a thin layer of fabric, complete the

electrical circuit. The key point is that the actual current passing through the body is very small, under three milliamperes, compared to the one-hundred-milliamperes current that is lethal to the heart. It is this high voltage that enables penetration through clothing and skin. Once the current stops, effects fully dissipate within a few minutes.

Technical Evolution: From Jack Cover to the Axon T10

The taser was first built in the early 1970s by the American inventor Jack Cover. In 1993, the company Axon, then named Taser International, brought the M26 model to market. The M26 used improved pulse technology and was, for the first time, welcomed by police forces as an alternative to a firearm in sensitive situations.

The next generation was the Taser X26, introduced in 2003. Its weight dropped to five hundred grams, half the previous model, its range reached seven meters, and, more importantly, it had internal memory to record the time and date of every discharge. The X2 model, released in 2011, had two separate barrels for sequential firing. In 2020, the T-Series family, including the X7, came to market with night-vision capability and an internal ballistic computer. The newest model, the Axon T10, was released in March 2026 for the Connecticut state police force. The T10's features include an intelligent safety lock system activated only by the authorized user's fingerprint, an internal 4K recording camera that captures thirty seconds before and sixty seconds after firing, and wireless connectivity to police servers.

The Taser on the Battlefield: From Police to Army

Is the taser a military weapon? The short answer: no, not for the front line. Most taser use in military settings is directed at military police, MP, and base guards, situations where controlling an intruding or intoxicated individual without killing him, and avoiding a media scandal, is necessary. Even so, assigning tasers to special-operations-forces fighters in covert operations has been raised. A taser can restrain a key guard without creating noise. But no official document confirms widespread taser use among combat forces. A Pentagon officer said in an interview that in a real combat situation, when the enemy has a helmet, body armor, and is armed, you never trust a taser; you trust your rifle.

Limitations, Risks, and Legal Controversies

The taser has never been an entirely harmless weapon. Numerous cases of death following taser shock have been reported. Even so, autopsies have shown that many of these deaths were linked to underlying factors, stimulant drug use, preexisting heart disease, head trauma from a fall after the shock, rather than directly to the electric shock itself. Newer models use triangular-shaped pulses with an intelligent feedback algorithm, but there is still no guarantee that a person with an underlying heart condition will not suffer complications after a shock.

From a military standpoint, the taser has other serious limitations. Its effective range is at most ten meters. The thin wires, the thickness of a human hair, tear easily. Thick or multi-layered clothing prevents the electrodes from reaching the skin. And, most importantly, on a real battlefield, there is no opportunity to carefully aim at the target. For these reasons, the taser is never regarded as a front-line combat weapon.

Part Three: Plasma Weapons: The Border Between Science and Fantasy

Among the three categories in this survey, plasma is without doubt the most controversial and complex. Plasma, the fourth state of matter, an ionized gas containing charged particles, ions and free electrons, is found in more than ninety-nine percent of the matter in the universe, including the sun and stars. But harnessing it as a portable, controlled weapon for destroying a target at a set distance is so difficult that many physicists place it at the border of the impossible.

What Is Plasma, and Why Is Building a Weapon from It Difficult?

To understand the problem, we must recall that plasma is created when gas is heated to millions of degrees Celsius and electrons are freed from their atoms. Three main obstacles stand in the way of building a plasma gun.

First, thermal instability and the need for magnetic confinement. Hot plasma has a strong tendency toward immediate expansion and disperses its energy as light and heat in every direction. To hold it in a narrow beam and direct it toward

a target, extraordinarily powerful magnetic fields are needed, something like a magnetic bottle. These bottles themselves require very heavy, energy-intensive, and fragile equipment. To date, the largest and most successful magnetic bottles humanity has built are those used in nuclear fusion projects such as the tokamak, structures the size of a building and weighing several thousand tons.

Second, a very limited propagation distance. A plasma cloud, after exiting the nozzle, becomes unstable on colliding with cool air molecules and disperses within a few meters, sometimes even a few centimeters. An Iranian physicist, Dr. Mohammad Mehdi Sheikh-Jabbari, has said on this matter that in the plasma environments humanity has built to date, or could build within the next ten to twenty years, controlled plasma propagation with significant energy at distances beyond a centimeter, the requirement for a plasma weapon, is not possible.

Third, enormous, non-portable energy sources. Creating a small plasma projectile with significant destructive energy, equivalent, say, to a grenade, requires power equivalent to tens of millions of watts. Storing and instantaneously releasing this energy in a portable package lies, in practice, at the boundary of today's physical capabilities.

MARAUDER: The World's Only Serious Project

The MARAUDER project, Magnetically Accelerated Ring to Achieve Ultrahigh Directed Energy and Radiation, was launched by the United States Air Force Research Laboratory in the early 1990s and is without doubt the most serious scientific effort in history to create a plasma weapon. The core idea was to build a coaxial railgun that would accelerate a dense ring, torus, of plasma to extraordinarily high speed. The first test of this gun was reported in August 1993. Researchers used a giant capacitor bank called Shiva Star, which stored roughly five to ten megajoules of energy. The test result was the launch of donut-shaped plasma rings that, on striking a target, produced severe mechanical and thermal shock as well as an electromagnetic pulse, EMP.

MARAUDER's long-term goal was to achieve plasma acceleration up to three thousand kilometers per second, reported in 1995, and ten thousand kilometers per second, a 2000 target. But from 2000 onward, this project's status has remained unclear. Some sources say its funding was cut and the air force shifted priority to solid-state lasers and microwave weapons. Others insist research has continued in classified form. What is certain is that no official evidence exists of a plasma weapon becoming operational in the American arsenal. Everything remains at the stage of early tests.

Claims and Controversies Surrounding Plasma Weapons in Iran

In recent years, a large part of the debate over plasma weapons has become entangled with claims by certain Iranian political officials.

In March 2025, a spokesman for Iran's Ministry of Defense announced the achievement of plasma technology, but did not explicitly say this technology had become an operational weapon. In April 2025, Mohammad Hossein Azimi, a member of parliament's National Security Commission, claimed the Sejil missile uses plasma fuel. He also said that Iran has over two hundred thousand ballistic missiles, over six hundred thousand missiles. On March 22, 2025, Sean Parnell, a Pentagon spokesman, claimed at a press conference that Iran is developing plasma weapon technology based on NASA satellite evidence, without presenting any credible image or document.

The reaction of scientists, however, was more direct. An Iranian physicist who asked not to be named told news agencies that producing plasma and launching it with significant energy at distances beyond a few centimeters is entirely outside the scientific and engineering capabilities of humanity today, and that such claims damage the credibility of Iran's scientific community. On the whole, the available evidence strongly suggests that all three parties, certain Iranian officials, the Pentagon spokesman, and affiliated media, have used plasma weapon for their own political purposes rather than pure scientific truth. The plasma weapon is, at present, a legend, not a combat reality.

Other Plasma-Related Military Research

Although the plasma gun as a direct weapon remains inoperative, other applications of plasma in the military domain are under development.

Plasma for camouflage and deception: researchers are studying plasma coatings that can absorb or deflect radar waves. The idea is that a thin plasma layer could be created around a tank or aircraft to sharply reduce its radar cross section.

Plasma to enhance the explosive power of conventional munitions: in 2024, the American army announced it was studying plasma-refined aluminum nanoparticles to increase the explosive power of conventional explosives. With this method, a munition's destructive power can be increased by up to thirty percent without increasing its weight.

Plasma to simulate nuclear explosions: in December 2024, the United States Department of Energy allocated 5.65 million dollars in funding to simulate nuclear explosions using plasma, without needing an actual nuclear test.

But all these cases remain very far from a plasma gun that fires plasma projectiles directly at an enemy.

Summary: The Triangle of Fire, Shock, and Ionized Gas

Each of the three weapon categories examined in this survey tells a different story of what it means to be new.

Flamethrowers carry the oldest idea. From Byzantine Greek fire to the backpack flamethrowers of the Second World War, and from there to today's thermobaric rocket launchers, this weapon has always been a symbol of terror and absolute annihilation. Today, systems such as Russia's TOS have become the most effective tool for clearing enemy trenches and urban areas. China's new generation of backpack flamethrowers shows that the idea of the direct fire fountain has not been entirely abandoned either, and is returning with more advanced technology.

Tasers, or electric guns, operate at the military-police border. They have, ironically, become a model of the ethical weapon, replacing killing with temporary nerve paralysis. But this ethical quality is relative, since dozens of deaths following taser shock have been reported. Even so, the taser can never take the place of a combat rifle at the front line.

The taser is a tool for military police and specific police operations, not full-scale war.

Plasma weapons, however, remain at the border of theory and fantasy. The most important legacy of projects such as MARAUDER is that they showed humanity that the extraordinary energy of plasma cannot easily be harnessed into a narrow, directed beam for combat. Three great obstacles, thermal instability, negligible propagation distance, and the need for enormous energy sources, have so far proven insurmountable. In the realm of political claims, the plasma weapon has become more a tool for exaggeration and media spectacle than a real weapon. Perhaps this very ambiguity and mystery is as effective in psychological warfare as a real weapon would be. But a physicist can never tell his student, go build a plasma gun that works on the battlefield. Such a thing does not lie within science's current horizon.

On the real battlefield of the twenty-first century, an infantry officer can, with a radio, call in a TOS system to turn the far side of a hill into hell with a thermobaric cloud of explosion. A military policeman can, with an Axon T10 taser, bring a violent protester to the ground within three seconds. But no soldier can yet aim a plasma gun at an enemy drone, and perhaps will not be able to for many years to come. The gap between real technology and imagination is most visible here. What we call a new weapon is sometimes the same hundred-year-old flamethrower that has only changed its skin, sometimes a restraint tool with blurred moral boundaries, and sometimes an alluring legend that has never left the laboratory. Understanding this difference is the task of every serious analyst of weaponry.

Special Feature

Imaginary Weapons: A Scientific Autopsy of Conspiracy Theories

The closing section of this research is a deep, comprehensive survey of the most famous conspiracy theories concerning weapons and military technology. The main goal at this stage is to separate reality from fantasy and to present a complete, documented picture of each of these controversial phenomena. Acknowledging that sometimes the facts are just as strange and astonishing as the legends, we examine each of these mistaken beliefs one by one below.

The Philadelphia Experiment (1943): A Legend Firmly Rooted in Fantasy

The Philadelphia Experiment is one of the most famous and enduring legends of contemporary history. The story goes that in 1943, the destroyer escort USS Eldridge, at the Philadelphia shipyard, using Einstein's unified field theory, became completely invisible and even, for moments, was displaced in time and space. Numerous recent investigations show that the foundation of this story has been shaky from the outset. This affair was first raised by Carl M. Allen, a retired sailor later found to have been born Carlos Miguel Allende and to have had a history of psychological problems. Accepting this story would mean believing that advanced scientific methods have been concealed for more than seventy years, while no credible evidence has ever been presented to prove it.

The Montauk Project: From Old Legends to the Formation of New Conspiracies

The Montauk Project, raised in the 1980s by Preston B. Nichols and Peter Moon, pseudonym of Vincent Barbarick, presents itself as a direct sequel to the Philadelphia Experiment legend. This theory claims that at Camp Hero air base at Montauk Point, Long Island, secret government experiments in time travel, mind control, and paranormal technologies were conducted.

New field investigations using declassified radar documents show that reality is worlds apart from these legends. At this base, a giant AN/FPS-35 radar, more than twenty-seven meters tall, with an output beyond five megawatts, had been installed. Declassified documents show this radar underwent various tests, including pulse-modulation tests, frequency-hopping sequences, and exercises coordinated with neighboring facilities. Local reports of the time attributed headaches, nausea, and a feeling of pressure in the air to the radar at the height of its operation. Importantly, this radar was part of the Cold War's early-warning network, used to detect Soviet bombers on the polar route, and was never used for hunting children or paranormal experiments. Interestingly, this base was closed in 1981, according to United States Department of Defense documents, and today is a tourist attraction and public park.

In 2025, new rumors circulated about this base's secret mechanisms and its connection to space aliens. But documentation shows these claims still trace back to the same old, largely uncitable sources. The fictional segments of *Stranger Things* are among the most notable works directly inspired by the Montauk legends, showing the profound influence of false beliefs on popular culture.

Nikola Tesla and the Death Ray: From the Power of Imagination to Reality

In 1934, Nikola Tesla, in a controversial interview, claimed to have built a device that could, with a focused particle beam, melt ten thousand enemy aircraft at a distance of four hundred kilometers. Journalists called this device the death ray, while Tesla himself called it the peace ray. Recent 2025 reviews show these claims contradicted the principles of physics from the outset. The core challenge is that maintaining such a beam's coherence over long distances, beyond absorption by the atmosphere, is fundamentally impossible. After Tesla's death in 1943, his documents and notes were examined by the electrical engineer John G. Trump at the Massachusetts Institute of Technology, MIT. The final conclusion was decisive: there is no credible evidence of a practical, usable design for building an advanced weapon.

By contrast, Tesla's ideas about particle beams have indirectly led to serious research into building various energy weapons, including laser and microwave systems. Tesla was a strange and astonishing figure, but the legendary fame of his death ray is more a product of media and inconclusive curiosity than a first-hand historical reality.

HAARP: A Conspiracy Theory That Still Sees Itself in Every Natural Disaster

The HAARP research project, High Frequency Active Auroral Research Program, located in Alaska, is presented by rumor-mongers as a weapon for controlling weather and creating earthquakes. The reality is that HAARP is a scientific center with 180 antennas that, by radiating a few megawatts of energy, studies the ionosphere layer and examines its effect on radio communications.

In 2025 and 2026, every major earthquake and storm was attributed to HAARP. For example, after the Myanmar earthquake of March 2025, which claimed more than 3,500 victims, widespread rumors immediately circulated on social networks linking it to HAARP. Luci Bellwood, communications director of the British Geological Survey, BGS, stated definitively on this matter that there is no reason to believe this earthquake was anything other than a natural event. Professor Bill McGuire of University College London also emphasized that Myanmar is one of the most

seismically active countries in the world, and this earthquake occurred on the main Sagaing fault, which marks the boundary between two tectonic plates.

In August 2025, as Storm Erin approached the American continent, social networks again claimed this storm too was the result of weather manipulation by HAARP. Finally, in 2025, documentary media outlets showed that the promotion of a monstrous NATO computer had also played a role in creating this atmosphere of rumor-mongering. Interestingly, Jessica Matthews, director of the HAARP program, has emphasized in conversation with fact-checkers that the research equipment at the HAARP site cannot create or intensify natural disasters. The American National Oceanic and Atmospheric Administration, NOAA, also announced in January 2026 that there is no scientific evidence of HAARP's effect on weather and earthquakes, and that its emitted energy is extremely negligible compared to the enormous flow of solar energy onto the atmosphere. No country in the world has the ability to create major earthquakes.

Aircraft Chemtrails: A Legend That Ignores the Laws of Physics

The chemtrail legend holds that the white lines behind aircraft actually contain toxic substances that governments spray to control population or alter climate. The reality is much simpler: these lines are, in fact, clouds of ice crystals that form when the hot, moist exhaust air of an aircraft engine meets the cold, dry air of the atmosphere. In other words, the chemtrail is a natural, physical phenomenon. Extensive scientific research has found no evidence of unusual chemical substances in this phenomenon. From the 1990s to 2025, the United States Environmental Protection Agency and other scientific bodies have repeatedly rejected this theory. In 2025, the American federal government spent significant funds creating official websites to correct this false belief.

Stranger still, in 2025, Florida state lawmakers passed a law requiring public airports to report any aircraft suspected of climate modification. This law has been sharply criticized from a scientific standpoint, and some experts have described it as enshrining conspiracy theory within policy. Even so, an international 2011 survey showed that roughly seventeen percent of the world's population believes in the existence of chemtrails. By contrast, the American National Science Foundation published a report in 2025 showing that the frequency of dense observation and prolonged persistence of this phenomenon in the age of climate change has increased owing to rising relative atmospheric humidity. That is, climate change, itself a real crisis, has apparently helped reinforce one of the century's greatest scientific falsehoods.

The Bermuda Triangle (2025): The Scientific Discovery Behind the Killer Waves

The Bermuda Triangle, a hypothetical triangle in the western North Atlantic, has for decades been a subject of debate and concern. Common belief holds that ships and aircraft mysteriously vanish in this region. But new scientific investigations show that the Bermuda Triangle is, more than anything, a victim of statistics and media sensationalism. In 2025, Lloyd's of London and the United States Coast Guard simultaneously announced that the rate of accidents and vessel disappearances in this region is not only not higher, but on average lower, than other busy world routes such as the Strait of Malacca and the North Sea. Lloyd's historical archive shows that many famous Bermuda Triangle incidents were simply copied and exaggerated by writers, with no new event having occurred at all.

In 2025, British researchers discovered that this triangle's geographic position is a special point for the synergy of weather systems. When storms from the south meet powerful waves from the north, terrifying waves beyond thirty meters high, called rogue waves, are created. These waves can easily break apart a vessel. Also, the presence of numerous islands in the Caribbean Sea creates complex water currents and errors in ships' compasses. In other words, the Bermuda Triangle has no supernatural property or unknown advanced technology. This region is very dangerous owing to its particular natural conditions, but its mystery has been entirely solved by the sciences of climatology, oceanography, and geology.

One of the more interesting events of 2025 was the circulation on social networks of images claiming to have discovered traces of the lost city of Atlantis in the depths of the Bermuda Triangle. These images were, in the shortest possible time, identified by fact-checking groups as a fabricated composite and a clear hoax, but they were viewed and shared hundreds of thousands of times, once again placing the Bermuda Triangle at the center of global attention.

Havana Syndrome (2025 to 2026): When Conspiracy Theory Meets Reality

The case of Havana Syndrome, or anomalous health incidents, is perhaps the most important example in which conspiracy theory and scientific reality have become dangerously intertwined. This affair began in late 2016, when dozens of American and Canadian embassy staff in Havana, Cuba, reported strange symptoms such as severe migraines, balance disorders, hearing problems, and memory issues. Some witnesses, including Mark Lenzi, a State Department security officer, heard a menacing sound resembling a metal arrow ringing in a funnel and believed their home had been attacked by a directed-energy weapon. Catherine Werner, another victim of these attacks, said she felt a strange pressure on her temples and later suffered vomiting and nosebleeds.

For years, American intelligence agencies were sharply divided over whether these attacks were real. In January 2025, the Office of the Director of National Intelligence, ODNI, published a report showing that of the country's seven intelligence agencies, five, including the CIA and FBI, stated it was very unlikely that a foreign country was behind these events. But surprisingly, two other agencies, based on new evidence, claimed that a foreign country's advancement in pulsed-microwave-weapon technology had been observed with very high probability in some of these cases. In February 2026, a 60 Minutes report on CBS added new dimensions to the affair: the American government had purchased a directed-energy weapon from a Russian criminal network and was testing it on animals. Media outlets and the Washington Post revealed that the CIA had also kept secret the details of a Norwegian-made microwave weapon. The House of Representatives demanded accountability from the Biden administration over the secret purchase of a pulsed weapon costing an eight-figure sum, tens of millions of dollars, said to be capable of fitting inside a backpack.

In mid-2026, with no final consensus yet reached on the origin of these events, the House Homeland Security Committee, led by Republicans, accused the Biden administration of a treacherous cover-up and deceiving the victims. These disagreements show that Havana Syndrome is a turning point for understanding directed-energy weapons in the future. What is certain is that this is no longer pure conspiracy, but a complex puzzle that has entangled governments, scientists, and journalists.

Final Summary

Return to the Beginning, a Look at the End

A Journey Without End

This book, or this collection of chapters, began with a simple question: when did humans first think of building tools to kill their own kind? But along the way, this question transformed into other questions: can peace be built from terror? Is a weapon only metal and gunpowder, or can thought and media also be weapons? Where is the border between fantasy and reality when it comes to weapons? And finally, will humanity ever be able to free itself from its own invention?

From Wood and Stone to the Atomic Bomb: An Irreversible Leap

The history of weaponry is a history of technological leaps. From the stone axe that the first humans chipped for hunting and defense, to the bronze sword that displaced empires, to gunpowder that brought down medieval walls, to the rifle that brought knights down from their horses, to the tank and the aircraft that made the battlefield three-dimensional, and finally the atomic bomb, which transformed the very concept of victory forever. At every step, it was thought that no further could be gone. But humanity has always gone further.

The thought-provoking point is that every technological leap in weaponry has been accompanied by a leap in terror. Not only terror of death, but terror of the quality of death; from suffocation by chlorine gas in the trenches of Ypres, to burning by mustard gas at Halabja and Sardasht, from the anthrax that unintentionally escaped a military facility in Sverdlovsk, to smallpox, eradicated yet still imprisoned in two laboratories of the world. This terror has forever blurred the line between waging war and crimes against humanity.

Nuclear Deterrence: The Greatest Lie That Came True?

The Cold War offered the world a theory never before systematically implemented: deterrence based on mutual assured destruction. In simple terms, if you kill me, I will kill you too, and we will both die. This theory, with all its logical and moral flaws, has for more than seven decades prevented a third world war. But is this peace, or a forced truce in the shadow of dread?

Some believe nuclear deterrence is the greatest lie that came true: no one truly believed the superpowers were so self-destructive as to set the world ablaze, but both sank so deeply into intelligence paranoia that they pulled back from every risk. Others say this theory worked only because the actors were rational and a madman never came to power. But in a world where arms-control treaties are eroding one after another and nuclear technologies are proliferating to more countries, will deterrence remain effective?

Perhaps the most important lesson drawn from Hiroshima and Nagasaki is that the nuclear weapon is no longer a weapon in the classical sense; it is an instrument for ending civilization. The survivors of those days, Akihiro, whose skin hung like burnt cloth, Tomiko, who was thirteen and suddenly grew old, their voices still echo in the ear of history: no one deserved this suffering. But has anyone listened?

Media: A Softer but Perhaps More Enduring Weapon

In this research, we saw that weapon no longer means only rifle and bomb. Media, in its various forms, has become the most powerful weapon of the twenty-first century. Social networks can, within a few hours, carry a rumor to the ears of millions, turn terrorism into martyrdom, and paint the enemy as a demon. In turn, those same media can narrate catastrophes and mobilize public opinion to prevent unjust wars.

But the dark side of media as a weapon is something we have felt deeply throughout this research: the planting of conspiracy legends as a tool for destroying public trust. From the Philadelphia Experiment to chemtrails, from HAARP to Havana Syndrome, we see how stories are built, exaggerated, and made believable, so much so that politicians sometimes pass laws based on them. In this space, the line between healthy doubt and destructive paranoia is thinner

than ever. The greatest harm of these legends is not financial cost but the erosion of public trust in scientific and democratic institutions. When people no longer know whom to believe, democracy grows sick, and the path opens for tyranny and chaos.

Eyewitness Testimony: A Truth No Weapon Can Kill

Amid the mass of statistics, treaties, and conspiracy theories, one constant, illuminating element remains: the voice of humans who testify from beneath the rubble, from behind barbed wire, from amid mustard-gas blisters, or after years of radiation-induced cancer. These voices, unlike baseless claims, cannot be forged or denied. A mother in Halabja whose child died in her arms, a Chernobyl liquidator who knew he would receive a lethal dose within forty-five seconds yet still climbed onto the reactor roof, a daughter of Hiroshima who spoke for peace at the United Nations, these accounts are a moral weapon against weapons of mass destruction.

Perhaps the greatest achievement of this research is the discovery that truth, however bitter and however late it sometimes emerges, always holds more power than lies. Thousands of pages of classified documents can be burned, but a survivor's memory cannot. Provided we are willing to listen.

The Future: In Search of Moral Deterrence

A review of these discussions shows that humanity is caught in a vicious cycle: threat, build a new weapon, mutual threat, build an even newer weapon, erosion of treaties, a graver threat. Will this cycle ever end?

Some believe only moral deterrence can offer a way forward: a level of public awareness in which the use of weapons of mass destruction becomes so taboo and repugnant that no government dares even look toward it, just as torture today, at least at the international level, is recognized as an unacceptable act. But reaching such a level requires generations of education, activating collective memory of past catastrophes, and, most importantly, rebuilding trust between governments and peoples, the very trust that conspiracy legends, information wars, and double standards have destroyed.

Closing Word

A Return to the Human

This research began with the history of weapons, but ends with the human. In the end, weapons are only objects, of metal, plastic, gunpowder, uranium, or electromagnetic waves. The will to use them, and equally the will to forbid them, arises from the human. Perhaps the most important question this research places before us is this:

Can humanity grow morally enough to permanently ground the tools it built for killing? Or is its history condemned to the endless repetition of weapons innovation and post-catastrophe regret?

The answer is not clear. But what is clear is that ignoring this question is itself the greatest danger. Today's generation, more than any other generation in history, holds in its hands the tools to see, hear, and share the truth. Each of us, by sharing the correct account, by promoting media literacy, by demanding transparency from governments, and by opposing conspiracy legends, can play a part in disarmament, not only nuclear or chemical disarmament, but the disarming of the mind from fear and distrust.

Weapons come and go. But humanity, if protected, endures. May this research be a spark for thinking anew about this simple yet difficult truth.

Afterword

Not an Ending, but a Pause Along the Way

This book, before it was the product of months of research and writing, was the product of years of questioning. Questioning myself, history, contemporary humanity, and a future that may no longer be so far off. When I first shared the idea of writing about the history of weaponry with a friend, he laughed and said, don't people have enough grief already? Why do you want to make them grieve more?

My answer that day was: so that we do not forget where our griefs came from. Today, having finished these chapters, I find my answer deeper: the history of weapons is the history of humanity's wounds. But these same wounds, if narrated correctly, can stitch awareness instead of pain.

Along this path, more than anything, I confronted contradictions. Humans who build a hospital with one hand and a bomb with the other. Humans who, on one day, strive to save a snow-covered child from beneath rubble, and on another day, target that same child with a missile. Humans who, in conference rooms, sign treaties banning chemical weapons, and in back rooms, fund the development program for those same weapons. This contradiction is rooted not in humanity's evil nature, but in the complex structures of power, fear, and distrust.

But amid this darkness, I also found things that gave me hope to continue: the courage of eyewitnesses who were not afraid to recount horrors, the perseverance of scientists who fought for transparency and truth, and grassroots movements that, in corners of the world, without fanfare, work for disarmament and peace. These, though less visible in the media, are the sturdy pillars of hope in our world.

Writing this research was, for me, a rite of passage. A passage from simplicity to complexity, from seeing in black and white to understanding shades of gray, and from despair to informed hope. Today, I hold neither the naive optimism of the path's beginning nor the absolute pessimism that no change is possible. Today, I believe that change begins slowly and imperceptibly, from the deeper layers of society, from classrooms, from writing desks, from friends' late-night conversations, and from the small decisions each of us makes in daily life.

If this research has managed to make even one reader think, think about the real costs of war, think about the credibility of information sources, and think about individual responsibility for preserving historical memory, then the effort has borne fruit.

In closing, I find it fitting to remember all the anonymous people who have spent their lives documenting atrocities, treating victims, and fighting weapons of mass destruction. Their names are not in textbooks, and their bodies rest beneath rubble or in remote graveyards. But the truth they narrated still shines.

And perhaps that very shining is enough to keep going.

With hope for a world in which this book, and these cries for peace, are no longer needed.

Spring 2026

The End

And perhaps, another beginning.

Appendix A

Glossary of Military and Technical Terminology

1. Negativity bias — the brain's tendency to process threats faster and more strongly than rewards.
2. Amygdala — the brain region responsible for threat detection and the fear response.

3. Hippocampus — the brain region that records spatial and temporal memories.
4. Anterior cingulate cortex — the brain region that generates a sense of ambiguity and unease.
5. Default distrust — the baseline stance of early humans toward strangers.
6. Levallois technique — an advanced stone-flaking method of the Paleolithic.
7. Cultural memory — knowledge and values stored and transmitted through objects.
8. Atlatl — a spear-thrower, a tool for launching a spear with greater range and force.
9. Persistence hunting — pursuing prey until it collapses from exhaustion.
10. Drive hunting — driving animals toward an ambush point or cliff.
11. Ambush — a surprise attack from a concealed position.
12. Taphonomy — the study of what happens to remains between death and fossil discovery.
13. Javelin — a light spear thrown by hand.
14. Camouflage — concealing one's appearance to blend into the environment.
15. Schöningen — an archaeological site in Germany with the oldest known wooden spears.
16. Olduvai Gorge — a major fossil site in Tanzania.
17. Krapina — a cave in Croatia with evidence of Neanderthal cannibalism.
18. Preemptive violence — attacking before the enemy has a chance to attack.
19. Asymmetrical casualty — a large disparity in losses between attacker and ambushed defender.
20. Burial rituals — ceremonies for interring the dead.
21. Shared myths — collective stories about a group's origin and identity.
22. Shared rituals — group ceremonies that reinforce cohesion.
23. Totemic myths — myths linking a group to a sacred animal.
24. Human sacrifice — the ritual killing of people for religious purposes.
25. Ritual violence — violence carried out within a religious ceremonial framework.
26. Scapegoat — a person or group made to bear collective blame.
27. Surrender — ceasing resistance against an enemy.
28. Prisoner of war — an enemy soldier captured in war.
29. Peace roads — routes on which war was forbidden and caravans were safe.
30. Neutral zones — areas where rival groups did not engage in conflict.
31. Shield — a defensive tool for blocking blows and projectiles.
32. Helmet — protective head covering.
33. Club — a simple wooden percussive tool.
34. Mace — a percussive weapon with a heavy head.
35. Stone mace — a mace with a stone head.
36. Stone axe.
37. Body armor — protective body covering.
38. Status symbol — a marker of high social standing.
39. Arms race — competition among states to produce superior weapons.
40. Sword.
41. Excalibur — the legendary sword of King Arthur.
42. Gram/Balmung — the legendary sword of Sigurd/Siegfried.
43. Kusanagi — the legendary sword among Japan's three imperial regalia.
44. Khopesh — the sickle-shaped sword of ancient Egypt.

45. Nandaka — the sword of Vishnu in Hindu mythology.
46. Ganjiang and Moye — two legendary swords in Chinese culture.
47. Projectile — any object thrown toward a target.
48. Sling — a tool for launching a stone with a cord or leather strap.
49. Longbow/English longbow — a 1.8-to-2-meter bow with high draw weight.
50. Composite bow — a bow made of wood, horn, and sinew.
51. Yumi — the asymmetric Japanese samurai bow.
52. Metallurgy — the science of extracting and working metals.
53. Smelting — separating metal from ore using heat.
54. Bronze — an alloy of copper and tin.
55. Iron.
56. Steel — an alloy of iron and carbon.
57. Siege warfare — military operations to capture fortified cities.
58. Battering ram — a heavy structure for breaking down gates and walls.
59. Testudo — the tortoise siege/shield formation.
60. Siege tower.
61. Belfry — another name for the siege tower.
62. Catapult — a machine for launching stones and bolts.
63. Torsion catapult.
64. Onager — a type of Roman torsion catapult.
65. Ballista — a bolt-throwing catapult resembling a giant horizontal crossbow.
66. Counterweight trebuchet — an advanced catapult with a heavy counterweight.
67. Moat — a water-filled trench around fortifications.
68. Arrow loops — narrow openings in a wall for defenders to fire through.
69. Counter-mine — a tunnel dug by defenders to counter attackers' tunneling.
70. Trace italienne — star-shaped fortifications built to counter artillery.
71. Gunpowder.
72. Fire lance — the first Chinese gunpowder weapon, a bamboo tube filled with powder.
73. Hand cannon — the first portable firearm.
74. Matchlock — a gun fired by a slow-burning match.
75. Flintlock — a gun fired by a flint spark.
76. Smoothbore — a barrel without rifling.
77. Rifled — a barrel with spiral grooves to spin the bullet.
78. Crossbow — a mechanism that fires a bolt using a trigger and catch.
79. Breech-loading — a gun loaded from the rear of the barrel.
80. Percussion cap — a small copper cap containing mercury fulminate.
81. Paper cartridge — a paper packet containing powder and ball.
82. Bolt-action — a gun loaded by manually operating a bolt.
83. Bayonet — a long blade fixed to the muzzle of a gun.
84. Citizen-soldier — a conscript soldier drawn from the general populace.
85. Levée en masse — a general call to military service.
86. Machine gun.

87. Gatling gun — a hand-cranked, multi-barrel machine gun.
88. Maxim gun — the first automatic, recoil-operated machine gun.
89. Trench.
90. No man's land — the area between two opposing front lines.
91. Creeping barrage — artillery fire that advances step by step ahead of infantry.
92. Shell shock — psychological trauma from intense bombardment, an early form of PTSD.
93. Artillery.
94. Field artillery — light, mobile artillery.
95. Heavy artillery.
96. Siege artillery — super-heavy artillery for destroying fortifications.
97. Howitzer — a short gun that fires in a high arc.
98. Indirect fire — firing without direct line of sight, using an observer.
99. Forward observer — a person who directs artillery fire.
100. Counter-battery radar — radar that locates enemy gun positions.
101. Self-propelled artillery.
102. Rocket artillery.
103. Katyusha — the famous Soviet rocket launcher.
104. MLRS/HIMARS — multiple-launch rocket system / High Mobility Artillery Rocket System.
105. Assault rifle — an automatic weapon firing an intermediate cartridge.
106. Sturmgewehr 44 — the first operational assault rifle.
107. Selective fire — the ability to choose between semi-automatic and fully automatic fire.
108. Tilting bolt — the locking mechanism of the StG 44.
109. Rotating bolt — the locking mechanism of the AK-47.
110. Long-stroke gas piston — the gas system of the AK.
111. Short-stroke gas piston — the gas system of many modern rifles.
112. Stamped steel — a cheap method of manufacturing a weapon's body.
113. Milled receiver — an expensive, precise method of manufacturing a weapon's body.
114. AK-47/AKM/AK-74 — the Kalashnikov family of rifles.
115. Direct impingement — the gas system of the M16.
116. M16/M4 — the standard American rifle.
117. Roller-delayed blowback — the special locking mechanism of the G3.
118. HK G3 — a German battle rifle, formerly Iran's standard weapon.
119. HK G36 — a German assault rifle made by Heckler & Koch.
120. FN FNC — a Belgian assault rifle.
121. Steyr AUG — an Austrian bullpup-design assault rifle.
122. Bullpup — a design placing the magazine behind the trigger for a shorter overall length.
123. Picatinny rail — the standard rail for mounting accessories on a weapon.
124. Polymer — durable plastic.
125. Striker-fired — a mechanism without an external hammer.
126. Red dot sight.
127. Holographic sight.
128. Sniper rifle.

- 129. Anti-materiel rifle — for destroying equipment and light vehicles.
- 130. SAW, Squad Automatic Weapon.
- 131. Battle rifle — a semi-automatic rifle firing a full-power cartridge, such as the G3.
- 132. Gas-operated — a mechanism using powder gas to cycle the action.
- 133. Recoil-operated — a mechanism using recoil force to reload.
- 134. Blowback — a simple mechanism for low-power cartridges.
- 135. Caliber — the internal diameter of a barrel or a bullet's diameter.
- 136. Cartridge — an integrated unit of bullet, powder, primer, and case.
- 137. Black powder.
- 138. Smokeless powder.
- 139. Full metal jacket, FMJ.
- 140. Hollow point, HP — banned in war.
- 141. Soft point, SP — banned.
- 142. Armor-piercing, AP.
- 143. Tracer round.
- 144. Incendiary round.
- 145. High explosive, HE round.
- 146. Rimfire/centerfire priming.
- 147. 9mm Parabellum — the standard NATO pistol cartridge.
- 148. .45 ACP — the powerful cartridge of the Colt M1911 pistol.
- 149. .50 BMG — the 12.7mm anti-materiel cartridge.
- 150. 5.56×45mm NATO — the standard cartridge of Western assault rifles.
- 151. 7.62×39mm — the legendary AK-47 cartridge.
- 152. 7.62×51mm NATO — the cartridge of battle rifles and light machine guns.
- 153. Caseless ammunition.
- 154. Tank.
- 155. Sloped armor — angled armor that increases effective thickness and deflects rounds.
- 156. Explosive reactive armor, ERA — armor that repels a round with its own small explosion.
- 157. Composite armor — ceramic, steel, and polymer combined.
- 158. Chobham armor — multi-layer composite armor.
- 159. Spaced armor — two layers separated by a gap.
- 160. Unmanned turret — crew housed in a separate hull capsule, not the turret.
- 161. Active protection system, APS — a system that intercepts incoming missiles.
- 162. Trophy — an Israeli active protection system.
- 163. Cope cage — an anti-drone metal cage on a tank turret.
- 164. M1 Abrams — America's main battle tank.
- 165. Leopard 2 — Germany's main battle tank.
- 166. Challenger 2 — Britain's main battle tank.
- 167. T-90 — Russia's main battle tank, an upgraded T-72.
- 168. T-14 Armata — Russia's new-generation tank with an unmanned turret.
- 169. Merkava — Israel's main battle tank, engine at the front.
- 170. Type 10/Type 99A — Japan's and China's main battle tanks.

- 171. Blitzkrieg — a German doctrine based on speed and coordination.
- 172. Deep battle — a Soviet doctrine for penetrating deep into enemy defense.
- 173. Combined arms — coordination of infantry, armor, air, and artillery.
- 174. Kesselschlacht — cauldron battle, encirclement and destruction of enemy forces.
- 175. Air superiority — the ability to operate freely in the sky without enemy interference.
- 176. Stuka, Ju 87 — the German dive bomber.
- 177. AWACS — Airborne Warning and Control System.
- 178. Zeppelin — a rigid German airship.
- 179. Synchronization gear — a system allowing a machine gun to fire through the propeller.
- 180. Fokker Eindecker — the first successful fighter with a synchronized machine gun.
- 181. Ace, flying ace — a pilot with five or more aerial victories.
- 182. Dogfight — close-range aerial combat.
- 183. Kamikaze — Japanese suicide pilots in the Second World War.
- 184. Interceptor — an aircraft or missile designed to counter bombers.
- 185. Stealth — radar-evasion technology.
- 186. Radar cross section, RCS — a measure of radar wave reflection.
- 187. Supercruise — supersonic flight without using the afterburner.
- 188. AESA, Active Electronically Scanned Array — an advanced radar type.
- 189. PESA, Passive Electronically Scanned Array — the generation before AESA.
- 190.IRST — infrared search and track, a passive thermal sensor.
- 191. Sensor fusion — combining data from various sensors into a single picture.
- 192. DAS — Distributed Aperture System, six infrared cameras on the F-35.
- 193. EOTS — Electro-Optical Targeting System.
- 194. HMDS — Helmet Mounted Display System.
- 195. F-22 Raptor — America's fifth-generation fighter.
- 196. F-35 Lightning II — America's fifth-generation fighter, three versions.
- 197. J-20 Mighty Dragon — China's fifth-generation fighter.
- 198. Su-57 Felon — Russia's fifth-generation fighter.
- 199. Dassault Rafale — France's 4.5-generation fighter.
- 200. Eurofighter Typhoon — Europe's 4.5-generation fighter.
- 201. B-2 Spirit — America's stealth strategic bomber.
- 202. Navy/naval warfare.
- 203. Submarine.
- 204. UUV, Unmanned Underwater Vehicle.
- 205. SSBN — ballistic missile submarine.
- 206. SLBM — submarine-launched ballistic missile.
- 207. Aircraft carrier.
- 208. Cruiser/destroyer.
- 209. Torpedo.
- 210. Mine, naval.
- 211. Mine, land.
- 212. Anti-personnel mine, APL.

- 213. Anti-tank mine, AT.
- 214. Ottawa Treaty — the 1997 treaty banning anti-personnel mines.
- 215. Hand grenade.
- 216. Fragmentation grenade.
- 217. Flashbang — a light-and-sound grenade for temporary blinding and deafening.
- 218. White phosphorus — an incendiary chemical substance.
- 219. Less-lethal weapon, NLW.
- 220. OC spray, pepper spray.
- 221. Taser — an electric shock weapon.
- 222. LRAD — a long-range acoustic device.
- 223. Chemical weapon.
- 224. Biological weapon.
- 225. Mustard gas — a highly persistent blistering agent.
- 226. Nerve gas — sarin, tabun, VX.
- 227. Unit 731 — a Japanese facility for biological weapons experiments on humans.
- 228. Nuclear deterrence.
- 229. ICBM — intercontinental ballistic missile, range beyond 5,500 kilometers.
- 230. MIRV — multiple independently targetable reentry vehicle.
- 231. Cruise missile.
- 232. Tomahawk, BGM-109 — an American cruise missile.
- 233. TERCOM — terrain contour matching, a guidance system comparing ground altitude to a stored map.
- 234. DSMAC — digital scene matching, comparing target images to stored images in the terminal phase.
- 235. Kalibr, 3M-54 — a Russian cruise missile.
- 236. Storm Shadow/SCALP — a French-British cruise missile.
- 237. Ballistic missile.
- 238. Boost phase — from launch to engine burnout.
- 239. Midcourse phase — flight outside the atmosphere.
- 240. Terminal phase — atmospheric reentry to impact.
- 241. Decoy — a false target to prevent interception.
- 242. CEP, Circular Error Probable — the radius within which fifty percent of rounds land.
- 243. Hypersonic weapon — speed beyond Mach 5 with maneuverability.
- 244. HGV, Hypersonic Glide Vehicle.
- 245. HCM, Hypersonic Cruise Missile.
- 246. Scramjet — a supersonic combustion jet engine.
- 247. Zircon, 3M22 — a Russian hypersonic missile, Mach 8-9.
- 248. Kinzhal, Kh-47M2 — a Russian air-launched hypersonic missile.
- 249. Avangard — a Russian hypersonic glide vehicle, Mach 20-27.
- 250. DF-17 — a Chinese ballistic missile with a hypersonic warhead.
- 251. Fattah — an Iranian hypersonic missile.
- 252. Anti-tank guided missile, ATGM.
- 253. Fire-and-forget — a missile needing no guidance after launch.
- 254. LOAL, Lock-on After Launch — a missile that finds its target after launch.

- 255. TOW, BGM-71 — an American wire-guided anti-tank missile.
- 256. Javelin, FGM-148 — an American fire-and-forget, top-attack anti-tank missile.
- 257. Spike — an Israeli third/fourth-generation anti-tank missile.
- 258. Kornet, 9M133 — a Russian laser-guided anti-tank missile.
- 259. NLAW — a Swedish-British light, single-use anti-tank missile.
- 260. Brimstone — a British anti-tank missile with millimetric radar guidance.
- 261. HJ-12 — a Chinese anti-tank missile, similar to Javelin.
- 262. RPG-7 — a Soviet shoulder-launched anti-tank rocket.
- 263. Dehlaviyeh — an Iranian missile, a copy of the Kornet.
- 264. Almas — a third-generation Iranian missile, a copy of Spike.
- 265. Drone/UAV — unmanned aerial vehicle.
- 266. UCAV — unmanned combat aerial vehicle.
- 267. Loitering munition — a suicide drone that patrols over a target area for hours.
- 268. Fixed-wing drone.
- 269. Rotary-wing/VTOL.
- 270. Quadcopter — a four-rotor drone.
- 271. MQ-1 Predator — America's first combat drone.
- 272. MQ-9 Reaper — America's heavy combat drone.
- 273. RQ-4 Global Hawk — America's strategic reconnaissance drone.
- 274. RQ-170 Sentinel — America's stealth drone, captured by Iran.
- 275. Shahed-136 — an Iranian loitering munition, known as the flying motorcycle.
- 276. Bayraktar TB2 — Turkey's combat drone.
- 277. Mohajer-6/Mohajer-10 — the Iranian drone family.
- 278. Ababil — Iran's oldest drone family.
- 279. Orlan-10 — a Russian tactical drone.
- 280. Lancet — a Russian loitering munition.
- 281. C-UAS, Counter-Unmanned Aircraft System.
- 282. RF jammer — radio-frequency jammer.
- 283. High-power microwave, HPM.
- 284. Autonomous swarm — coordination of hundreds of drones without centralized command.
- 285. C4ISR — command, control, communications, computers, intelligence, surveillance, reconnaissance.
- 286. Network-centric warfare, NCW.
- 287. Common operational picture, COP — an integrated digital map of the battlefield.
- 288. Data fusion — combining raw data from various sources.
- 289. Electronic warfare, EW — operations to control the electromagnetic spectrum.
- 290. Jamming — disrupting an enemy signal.
- 291. Frequency hopping — rapidly changing frequency to prevent jamming and interception.
- 292. System of systems, SoS.
- 293. RWR, Radar Warning Receiver — a system that detects enemy radars.
- 294. GPS, Global Positioning System.
- 295. INS, Inertial Navigation System — calculates position using accelerometers and gyroscopes.
- 296. FLIR, Forward-Looking Infrared camera.

- 297. Algorithm — a step-by-step set of rules for solving a problem.
- 298. Artificial intelligence, AI — a machine's capacity to imitate human cognitive functions.
- 299. Machine learning, ML.
- 300. Deep learning — an advanced form of ML using multi-layer neural networks.
- 301. Rule-based system.
- 302. False positive/false negative — a type-one error, false alarm, and a type-two error, missed real threat.
- 303. Hyperwar — war at machine speed, with millisecond decision-making.
- 304. Project Maven — the Pentagon's deep-learning-based system.
- 305. Havana syndrome — neurological symptoms reported by American embassy staff in Cuba.
- 306. Directed-energy weapon, DEW.
- 307. Solid-state laser — a laser with a solid, crystal, gain medium.
- 308. Gain medium — the material in which light is amplified in a laser.
- 309. Pump source — the energy source that excites electrons.
- 310. Optical cavity — two mirrors on either side of the gain medium.
- 311. Beam combining — combining the beams of several lasers to increase power.
- 312. LaWS — the United States Navy's laser system, 2014.
- 313. HELIOS — America's 150-kilowatt laser system.
- 314. Iron Beam — Israel's laser system.
- 315. Peresvet — a Russian dazzler laser.
- 316. Silent Hunter — China's export laser system.
- 317. Seraj — Iran's laser system.
- 318. Flamethrower.
- 319. Thermobaric weapon — a vacuum weapon.
- 320. TOS-1, Buratino — a Russian thermobaric rocket launcher.
- 321. Plasma weapon — mostly theoretical.
- 322. MARAUDER — the American air force's plasma project, 1990s.
- 323. Conspiracy theory.
- 324. Chemtrail conspiracy theory — the false belief that aircraft disperse chemicals.
- 325. HAARP — an ionospheric research program in Alaska, a target of conspiracy theories.
- 326. Bermuda Triangle — a region of the Atlantic associated with mysterious incidents, a legend.
- 327. Philadelphia Experiment — a legend.
- 328. Montauk Project — a legend.
- 329. Rogue wave — an extremely tall, unexpected ocean wave.
- 330. EMP, Electromagnetic Pulse — a burst of electromagnetic energy that disables electronics.
- 331. IED, Improvised Explosive Device.
- 332. Mortar — a short gun that fires in a high arc.
- 333. Grenade launcher — a weapon that launches a grenade using gas or powder pressure.
- 334. Cavalry — mounted military forces, before the tank age.
- 335. Phalanx — the dense infantry battle formation of ancient Greece.
- 336. Legion — the main unit of the ancient Roman army, four thousand to six thousand soldiers.
- 337. HEAT, High Explosive Anti-Tank ammunition.
- 338. HESH, High Explosive Squash Head ammunition.

- 339. APFSDS — armor-piercing fin-stabilized discarding sabot.
- 340. NERA, Non-Explosive Reactive Armor.
- 341. Ballistics — the science of projectile motion.
- 342. Muzzle velocity — a bullet's speed on leaving the barrel.
- 343. Stopping power.
- 344. Overpressure — excess pressure from an explosion.
- 345. Spalling — interior armor fragmentation.
- 346. Tandem charge — a two-stage warhead.
- 347. Cordite — a type of smokeless powder.
- 348. Nitroglycerin.
- 349. Nitrocellulose, gun cotton.
- 350. Frangible — a fragmenting practice round.

Appendix B

Chronology of Key Events in the History of Weapons

Prehistory (to 3000 BCE)

- 2.6 million years ago — the first stone tools, the Oldowan industry, in East Africa.
- 1.7 million years ago — the two-faced Acheulean hand axe, the first tool with standardized, symmetrical design.
- 500,000 years ago — evidence of the first controlled use of fire by Homo erectus.
- 300,000 years ago — the Schöningen wooden spears, Germany, the oldest evidence of cooperative hunting.
- 100,000 years ago — the first ritual burials, Neanderthals at Shanidar, Iraq.
- 50,000 years ago — long stone blades, the first tools dedicated to cutting and wounding.
- 30,000 years ago — invention of the spear-thrower, atlatl, increasing throw range and force.
- 20,000 years ago — the first bows, indirect evidence from stone arrowheads in Africa.
- 14,000 years ago — the Jebel Sahaba cemetery, Sudan, the oldest evidence of organized warfare.
- 12,000 years ago — the beginning of the Neolithic, agriculture and village life, in the Fertile Crescent, a sharp rise in border violence.
- 8,000 years ago — the first stone walls and watchtowers, Jericho, Palestine.
- 5,000 years ago — copper smelting and casting on the Iranian plateau and in Mesopotamia, the end of the Stone Age.

Antiquity (3000-500 BCE)

- 3300 BCE — the Bronze Age; the bronze sword in Mesopotamia and Anatolia.
- 2500 BCE — Sumerian war chariots, the first combined weapon, mobility plus firepower.
- 1200 BCE — the Bronze Age collapse, transition to the Iron Age. The Trojan Horse, legend.
- 1200-1000 BCE — the spread of iron weapons in the Middle East, the Hittites, the Philistines, the Israelites.
- 700 BCE — the first catapults, Greece and Assyria.
- 550 BCE — formation of the Achaemenid army, heavy cavalry, archers, scythed chariots.
- 480 BCE — the Battle of Salamis, the decisive role of trireme ships and strait tactics.
- 330 BCE — Alexander's siege of Tyre, use of massive siege towers and a land causeway.

300 BCE — the ballista and torsion catapult in Greek and Roman armies.

200 BCE — chainmail among the Celts and later the Romans.

The Classical Era and the Middle Ages (500 BCE to 1400 CE)

50 BCE — Roman legions equipped with the short sword, gladius, and lorica segmentata armor.

300 CE — cataphract cavalry, Sasanian Iran and the Eastern Roman Empire, full armor for man and horse.

678 CE — first use of Greek fire, a flamethrower, by Byzantium against the Arabs.

700-900 CE — spread of the stirrup in Europe, the birth of the armored knight.

1000-1100 CE — invention of the composite bow, wood, horn, sinew, by steppe nomads.

1140 CE — the first rules banning the use of the bow and crossbow against civilians, the Second Lateran Council.

1225 CE — the treatise al-Furusiyya, on weapons and horsemanship, in Syria.

1260 CE — the Battle of Ain Jalut, the first encounter with Mongol hand cannon.

1326 CE — the first depiction of a cannon in Europe, gunpowder had been developing in China since the ninth century.

1346 CE — the Battle of Crécy, the English longbow against French knights.

1453 CE — the fall of Constantinople, massive Ottoman cannon bring down the Theodosian Walls.

The Age of Gunpowder and the Military Revolution (1400-1800)

1495 — the first cannon mounted on European ships.

1503 — the Battle of Cerignola, Spanish musketeers crush French knights, the end of the age of chivalry.

1514 — the Battle of Chaldiran, Ottoman gun and cannon against Safavid sword and bow.

1525 — the Battle of Pavia, Spanish marksmen pierce knights' armor.

1571 — the Battle of Lepanto, the last great battle fought with oared ships.

1609 — the first operational submarine, Cornelius Drebbel, the Netherlands.

1750-1800 — development of the flintlock and bayonet, the end of cavalry dominance.

1798 — Napoleon's Egyptian campaign, artillery becomes the god of war.

1805 — the Battle of Trafalgar, line-of-battle tactics reach their peak.

1806 — the end of full-armor production in European armies, except the breastplate.

The Industrial Age and the World Wars (1800-1945)

1836 — invention of the percussion cap, firing in the rain becomes possible.

1859 — the Battle of Solferino, the beginning of the Red Cross movement and humanitarian law.

1861-1865 — the American Civil War, the Battle of Hampton Roads, ironclads, the first hand-cranked machine guns, Gatling.

1866 — the Battle of Lissa, use of ramming at sea.

1870-1871 — the Franco-Prussian War, steel artillery and bolt-action rifles.

1884 — the Maxim machine gun, the end of the age of linear advance.

1899 — the Hague Convention, banning the use of expanding bullets in war.

1903 — the Wright brothers' first flight, the birth of the third dimension of war.

1906 — HMS Dreadnought, a revolution in warships.

1914-1918 — the First World War: chlorine gas at Ypres, 1915, the tank at the Somme, 1916, aerial fighters, the Fokker Eindecker.

1925 — the Geneva Protocol, banning the use of poison and biological gases.
 1936-1939 — the Spanish Civil War, Germany and Italy test blitzkrieg.
 1939-1945 — the Second World War: blitzkrieg, 1940, the Battle of Britain, 1940, the Battle of Midway, 1942, the Battle of Kursk, 1943, kamikaze, 1944-1945.
 1945 — the atomic bombing of Hiroshima and Nagasaki, the end of the Second World War and the beginning of the nuclear age.

The Cold War and the Nuclear Age (1945-1991)

1947 — the Truman Doctrine, the beginning of nuclear deterrence. Design of the AK-47.
 1949 — the first Soviet atomic bomb, the end of the American nuclear monopoly.
 1950-1953 — the Korean War, the first large-scale jet fighter engagement, the F-86 against the MiG-15.
 1954 — the nuclear submarine USS Nautilus.
 1955-1975 — the Vietnam War: attack helicopters, the UH-1 Huey, the RPG-7, the B-52 bomber, Agent Orange.
 1960 — the first ballistic-missile submarine, USS George Washington.
 1962 — the Cuban Missile Crisis, the closest point to full-scale nuclear war.
 1967 — the Six-Day War, Israeli air superiority, Operation Focus.
 1969 — the first flight of the Boeing B-52, early versions from 1952.
 1972 — the last Apollo mission, the end of the space race.
 1973 — the Yom Kippur War, anti-tank missiles, the Sagger and RPG, target tanks.
 1979-1989 — the Soviet war in Afghanistan, American Stingers against Russian helicopters.
 1980-1988 — the Iran-Iraq War, extensive use of chemical weapons, Sardasht, Halabja. Missile attacks, Shahabs against cities.
 1983 — Reagan's Strategic Defense Initiative, Star Wars.
 1989 — the fall of the Berlin Wall. The last recorded aerial engagement of an American F-14 Tomcat against a Libyan MiG-23.

The Information Age, Drones, and Artificial Intelligence (1991-2026)

1991 — Operation Desert Storm, the Gulf War, the first C4ISR war and extensive use of cruise missiles, Tomahawk.
 1993 — the Chemical Weapons Convention.
 1994-1996 — the Chechen War, Russia's first tactical drone operations.
 1997 — the Ottawa Treaty, banning anti-personnel mines.
 1999 — NATO's bombing of Yugoslavia, the first combat use of the B-2 stealth bomber.
 2001 — the September 11 attacks, the beginning of the war on terror. Introduction of the armed RQ-1 Predator with Hellfire missiles.
 2003 — the invasion of Iraq, the fall of Saddam. The peak of Kevlar vest and ceramic plate use.
 2006 — the Second Lebanon War, the Trophy active protection system, Israel, against Kornet missiles.
 2009 — establishment of United States Cyber Command, USCYBERCOM.
 2011 — the killing of bin Laden in Pakistan by American special forces, the role of drones. NATO intervention in Libya.
 2014 — the annexation of Crimea and the start of the war in Donbas, electronic warfare and drones.
 2015 — the rise of ISIS, mass use of armed commercial drones and loitering munitions.

2020 — the assassination of General Soleimani by an MQ-9 Reaper drone. The Nagorno-Karabakh war, Azerbaijan's victory with Bayraktar and Harop drones.

2022-2026 — the war in Ukraine, the first large-scale drone war, Shahed-136, Lancet, FPV. The vital role of Starlink and artificial intelligence. The arrival of hypersonic missiles, Kinzhal, Zircon, on the battlefield. Official announcement of Iran's Fattah hypersonic missile.

2024-2026 — the conflict in Gaza, the AI-based Habsora fire-direction system. Intensification of cyber and network warfare.

2025-2026 — introduction of the first combat units equipped with 100-kilowatt lasers, Israel, the United States, China. Beginning of mass production of autonomous swarming drones.

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